FACTORS INFLUENCING DISTRIBUTION OF AQUATIC MACROPHYTES IN A SMALL NORTHWESTERN ONTARIO LAKE

A thesis

submitted for the degree of

Master of Science

by

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March, 1970

Thunder Bay, Ontario

ABSTRACT

In October, 1968, 5.0 Kilograms of wild rice (Zizania aquatica L.) seed were planted at 11 selected sites in Grassy Lake, in an attempt to introduce a self-sustaining crop. Some success was obtained at all sites, subject to the various effects of wind and wildfowl. As a sound understanding of the aquatic environment was necessary before further research could be carried out in connection with the wild rice, the temperature relations, of primary importance in all limnological investigations, were chosen as the subject of this study.

Temperatures in air, water, and soils were measured by a series of 55 thermocouple units, mounted on 4 standards established in line across the shore zone. Sixteen sets of weekly and diurnal readings illustrate a pattern of uniform temperature in the vertical water column, and the lack of any evidence of seasonal thermal stratification in the water mass. Turbidity in varying degrees was present at all times, and with increased adsorption of solar radiation in the upper layers of the lake, mean water temperatures remained higher than mean air temperatures.

The distribution of heat in the surface layers of the water was found to be relatively uniform, and temperature checks made throughout the depth of the lake supported the findings at the thermocouple station.

Heat energy was found to be readily transferred to the bottom sediments, and mean temperatures for the first 20 centimetres of the substrate remained within a few centigrade degrees of the temperature of the vertical water column.

Grassy Lake, situated near the southern tip of Sibley Peninsula, on the north shore of Lake Superior, is exposed to the force of the wind, and comparative anemometer readings give strong support to this fact. The wind is believed to be instrumental in the constant turnover and mixing of the lake waters, and to a considerable extent in governing the distribution of the aquatic macrophytes in the region of the shore.

ACKNOWLEDGEMENTS

The author wishes to express his deep gratitude to Dr. P. Barclay-Estrup whose interest, encouragement, constructive criticism, and patient guidance have made the completion of this work possible, and are very greatly appreciated.

I should also like to express my sincere appreciation to:

Dr. W. M. Graham, Chairman, Department of Biology, Lakehead University, for his continued interest and encouragement.

Dr. F. L. Waterhouse, University of St. Andrews, for his advice with regard to the measurement of temperature.

Dr. R. Freitag, Department of Biology, Lakehead University, for his assistance in the identification of members of the aquatic animal community.

Mr. Claude E. Garton, Curator, C. E. Garton Herbarium, Lake-Head University, for his valued assistance in identification and verification of plant species.

Mr. D. Dutchak and Mr. G. Hashiguchi, of the technical staff of the Department of Biology, for their unstinting assistance in the field and in the laboratory.

Mr. C. A. Elsey, Ontario Department of Lands and Forests, Port Arthur, for his interest in the project, his kindness in obtaining wild rice seed, and for his permission to use the facilities of Sibley Provincal Park. And to Mr. Gene Murphy, Park Superintendent, for his interest and cooperation throughout all phases of the field work.

Mrs. S. Halter, Mr. James D. Cross, Mr. S. R. Holloway, and Mr. Jules G. Cross, of the Silver Islet community, for their kindness in providing not only invaluable information with regard to the geology and past history of the Grassy Lake area, but for the physical assistance offered so freely and willingly in times of great need.

Lakehead University, for the opportunity to undertake such a study, and for the cooperation and understanding forthcoming from all personnel.

Ontario Department of University Affairs for a grant that provided part of the funds required for this research.

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CHAPTER I

INTRODUCTION

INTRODUCTION

Grassy Lake is situated near the tip of Sibley Peninsula, on the north shore of Lake Superior, and is typical of many small bodies of water to be found in the Sibley area. Glacial in origin, and quite often shallow in nature, these lakes are strongly influenced by the sedimentary rock formations dominating the peninsula. Although Grassy Lake is referred to as a lake, it has many of the basic characteristics of a pond (Hohne in Geiger 1961). The lake is shallow, with a maximum depth of 1.2 metres, an area of approximately 6 hectares, and is relatively exposed to the action of the wind.

A study of environmental factors influencing the distribution of aquatic macrophytes in Grassy Lake, was undertaken during the late spring and summer of 1969.

The importance of such work in the small and shallow lakes of the boreal regions cannot be stressed too highly at this time. The boreal zone holds considerable future value in human recreation as well as wildlife conservation, and a thorough understanding of the basic processes at work in the plant and animal communities of the area, both terrestrial and aquatic, will permit man to use this ecosystem to the greatest advantage of all concerned without depletion of the potential beyond the point where recovery is possible. As far as can be determined, no previously published work is available for limnological studies in this particular geographic area, in connection with small lakes.

An attempt was made to ascertain the reasons for the existing distribution of aquatic vegetation with respect to the topography of the shoreline and the environmental factors involved. The basic problem was to assess those factors of the environment of the littoral shelf and immediate vicinity which might influence the structure of the aquatic communities, and be instrumental in the success or failure of an introduced species such as wild rice (*Zizania aquatica* L.).

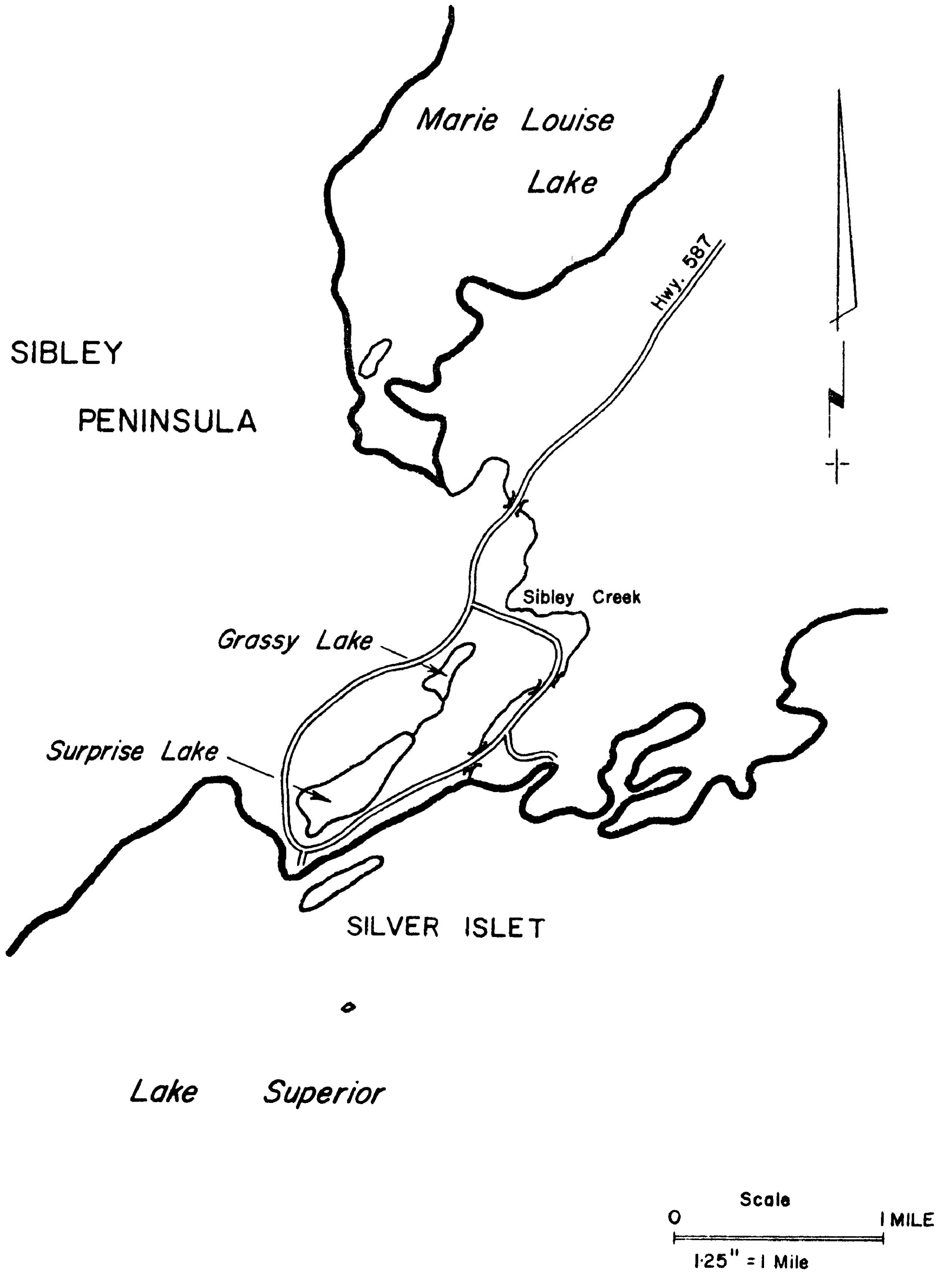
A small quantity of wild rice was introduced into Grassy Lake during the fall of 1968. The environmental factors contributing to the success of the plant are of primary interest. Because of the economic potential of the grain as an introduced or cultivated crop, considerable interest has developed around the use of hitherto unproductive (with respect to wild rice) lakes and rivers as future growing sites.

Ruttner (1963) considers the temperature factor to be basic to all aquatic studies. Temperature does indeed affect, directly or indirectly, most of the processes at work in the ecosystem. Therefore this factor has been discussed under a separate heading. However, Sculthorpe (1967) feels that temperature alone cannot be responsible for the distribution of aquatic vegetation. He agrees with Spence (1967) that the movement of air, the chemical status of the water, the chemical and physical status of the substrate, and the availability of light, are all of paramount importance. Because of the stress placed on the effects of the wind in influencing the distribution of aquatic macrophytes by Sculthorpe (1967) and Spence (1967), measurements were made of wind velocities on the surface of Grassy Lake from all points of the compass.

Analysis of the aquatic ecosystem is not possible without due consideration to all factors involved. Therefore initial observations were made with respect only to pH of soils and water, organic content and water-retaining capacity of the soils, precipitation and water levels. These factors have been included in the section dealing with the description of the site, in an attempt to give a more balanced picture prior to the detailed work on temperature alone.

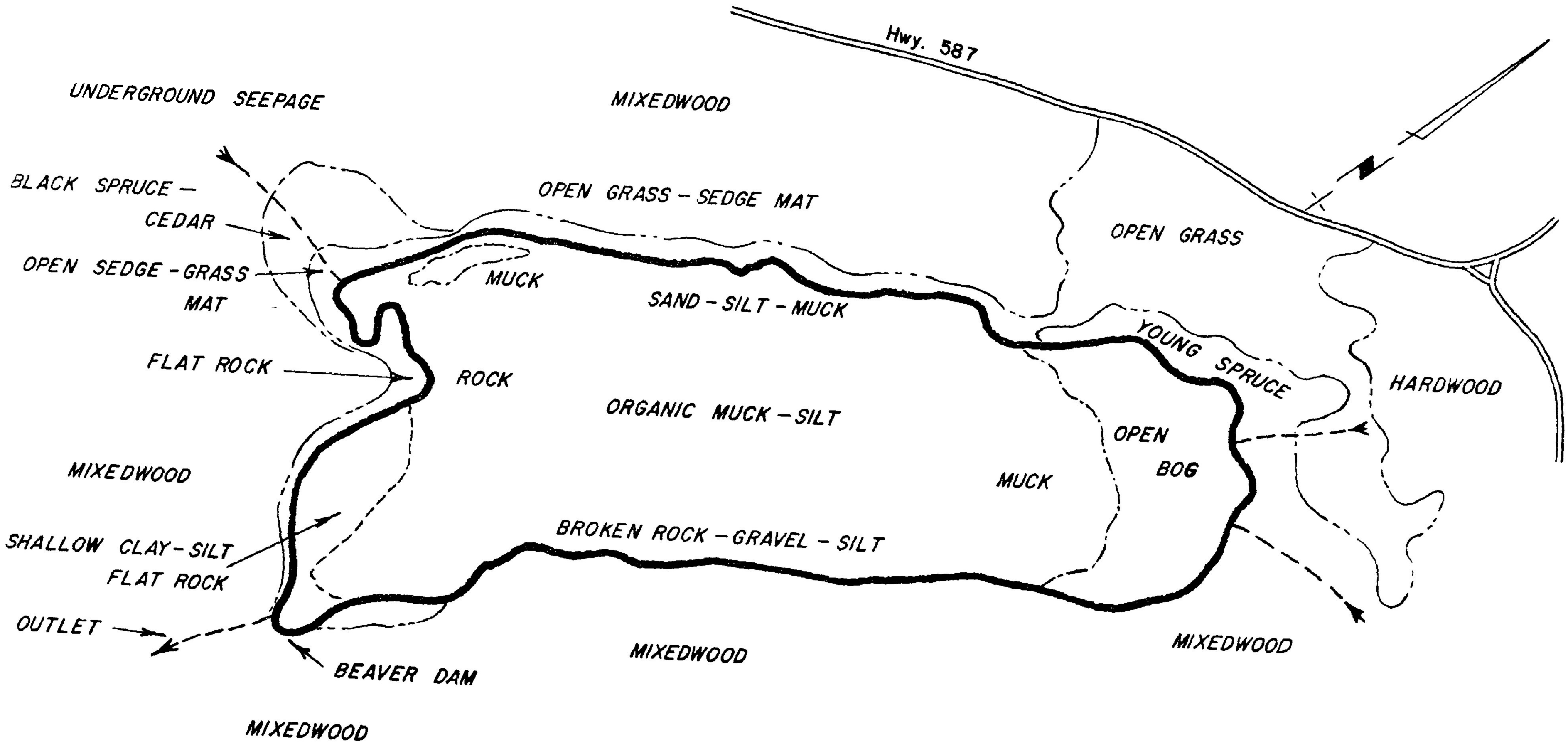
CHAPTER II

DESCRIPTION OF THE SITE AND VEGETATION



LOCATION OF GRASSY LAKE

(LITTLE SURPRISE LAKE)



LATITUDE : 48° 21' N

LONGITUDE : 88° 49' W

GRASSY LAKE

SCALE : 1 Centimetre = 30 Metres

DESCRIPTION OF SITE

PHYSICAL ASPECTS I.

Location:

Grassy Lake is located close to Highway 587, between 2.4 and 3.2 Kilometres (1.5 and 2.0 miles) northeast of the old mining community of Silver Islet, which is situated near the tip of Sibley Peninsula on the north shore of Lake Superior. Latitude 48° 21' N., longitude 88° 49' W.

Geology:

Except for numerous diabase dykes, and the large diabase sill forming the upper part of the Sleeping Giant near the tip, the peninsula is underlain entirely by stratified sedimentary rocks (Pye 1962). In the Grassy Lake area, outcroppings of red, impure dolomites and dolomitic limestones are to be found (J. G. Cross, personal communication).

Topography:

No detailed survey was made of the area under study, and the following information was taken from the Department of National Defence Sheet No. 52 A/7 West.

Grassy Lake, approximately 425 metres in length and 150 metres in width, is situated in a shallow trough at an elevation of 220 metres (725 feet) above mean sea level, or 38 metres (125 feet) above the mean level of Lake Superior.

The long axis of the lake, and the trough, run in a northeast-southwest direction. Approximately 0.8 Kilometres (0.5 miles) to the northwest of the lake, and running parallel to the shoreline, a ridge rises abruptly to an elevation of about 280 metres (925 feet) above mean sea level. On the opposite, or southeast shore, a hill rises directly from the edge of the water, with a slope of between 25^{o} and 35^{o}, to an elevation of approximately 244 metres (800 feet) above mean sea level.

The terrain at the northeast end of the trough rises gently away from the lake, while that at the south corner drops towards Suprise Lake, which has an elevation of 198 metres (650 feet) above mean sea level. The land rises from the west corner to an elevation of 247 metres (810 feet), within a distance of 0.6 Kilometres.

Drainage:

The drainage basin of the lake is small, measuring approximately 1200 metres by 700 metres. The inlets to the lake are not obvious during the summer months, and consist mainly of seepage through the surface vegetation at the northeast and west corners. There is evidence of additional seepage of ground water at numerous locations along the shore. During the spring run-off period, however, considerable surface flow is evident at both the northeast end andthe west corner.

History:

There is some indication that Lake Marie Louise may, at one time, have drained through what is now the Grassy Lake area, and via Surprise Lake, to Lake Superior. The terrain at the northeast end of the lake rises gently to a ridge of sand, which drops abruptly to the present site of Sibley Creek. This ridge takes on the configuration of an ancient beach. Sibley Creek travels directly towards Grassy Lake from Lake Marie Louise, veering sharply to the left as it strikes the coarse gravel and rock deposits underlying the sand deposits on the northeast side, at a point about 325 metres from the northeast end of Grassy Lake (J. G. Cross, personal communication).

The mature mixedwood forests that originally made up the dominant vegetation of the lake basin, have been heavily logged over the past 100 years for mining and house timber, sawlogs, and pulpwood. The majority of the remaining forest cover is mature to overmature mixedwood, with some immature to mature softwoods in the understorey.

The shoreline of the lake is strewn with well preserved dead-fall of *Thuja occidentalis* L., *Picea mariana* (Mill.) BSP, and *Larix laricina* (Du Roi) K. Koch. This material has remained thus for a period of at least 32 years (J. D. Cross, personal communication).

There is evidence to indicate that beaver were active in the area at some time in the past. The dam at the south corner of the lake, the remains of two ancient houses, as well as numerous felled trees and old stumps, point to the fact that this was an important habitat. The damage to the trees once located along the shore of the lake, is probably the result of flooding, and this fact would lend support to the hypothesis.

Photograph No. 1

The northeast end of Grassy Lake, looking east from the north corner of the lake. The mat of marsh vegetation is visible in the centre of the picture; the extension of the slope rising from the southeast shore is seen in the upper right corner; the accumulation of dead-fall, and the grass-sedge mat, in the foreground and left centre.

Photograph No. 2

The northwest shore of Grassy Lake, looking south-west from the thermocouple installation. The grass-sedge mat and the accumulation of deadwood is well illustrated in this picture. The mat-forest boundary is visible at left centre.

PHYSICAL ASPECTS II.

The Lake - General Description:

The lake is shallow, with a maximum sounding to the surface of the bottom ooze (Schlamm, in Ruttner 1963) varying between 100 and 120 centimetres. A rock shelf is in evidence at the south corner, and runs along the southwest shore to a point about halfway to the west corner. Broken boulders, rock and gravel make up the shoreline at the foot of the slope along the length of the southeast shore. With the exception of the mats of vegetation at the northeast end and the west corner of the lake, the remainder of the shore consists of packed yellow sand.

The bottom of the lake is covered by a thick layer of dark brown to black ooze. This layer thins as it approaches the shore, reaching a limit in water depths of between 30 and 50 centimetres. At this point, the broken rock, gravel, or sand substrate become exposed to varying degrees. Some organic sediments are evident between the edge of the ooze and the shoreline, and often consist of a fine black muck mixed with larger pieces of undecomposed organic materials. A buildup of these sediments is found mainly in the slight depressions in the bottom contours, among the broken boulders and rocks, in the sheltered depressions in the shoreline, and trapped among the stems of the aquatic vegetation.

Water Level:

A 2.5 centimetre square hardwood stake, calibrated in centimetres, and tied in by means of level and rod with a steel reference bar located 15 metres back from the shoreline, was established in approximately 35 centimetres of water, on June 8, 1969. The site chosen was in the vicinity of the thermocouple standards, where protection from wave action was available.

Readings were taken once a week, at about 1000 hours on Sundays, over the period from June 8th to October 12th, 1969. A summary of the data obtained may be found in Appendix A, and Figure No. 3 illustrates the variation in the level of the lake during the period of the study. A maximum fluctuation of 27 centimetres was observed over the period of study.

Precipitation:

A Standard British Rain Gauge was installed, with the rim 30.5 centimetres (12") above the level of the ground, in an open area at Silver Islet, on June 8, 1969. Readings were taken once a week, at approximately 0900 hours on Sunday mornings, over a period from June 15th to October 12th, 1969.

A correction factor of 1% was applied to the weekly reading to allow for evaporation (Platt & Griffiths 1964).

A summary of the data obtained may be found in Appendix B, and Figure No. 4 illustrates the cummulative precipitation over the period of the study.

The summer of 1969 was characterized by clear, hot weather, and relatively little precipitation. The level of the water in Grassy Lake was reported to have been the lowest in 20 years (S. R. Holloway & J. D. Cross, personal communication). As a result, much of the normally submerged shoreline was exposed, and species such as *Sagittaria latifolia* Willd., *Eleocharis palustris* L., *Eleocharis acicularis* (L.) R. & S., *Equisetum fluviatile* L., *Zizania aquatica* L., and *Sparganium* sp., were found, by late August and early September, to be growing above the level of the water, on sand, muck, clay-silt, and fine gravel soils.

A coefficient of correlation (Kershaw 1964) of +0.83 was determined for the relationship between the precipitation and the water level of the lake, for the period from June 15th to October 12th, 1969. While a definite, positive relationship is indicated, it is expected that some variation will become apparent as the moisture content and temperature of the air, the rates of evaporation and transpiration, the nature and density of the ground cover, the intensity and angle of the incoming radiation, and the moisture content of the soils change throughout the spring, summer and fall seasons.

Figure No. 3

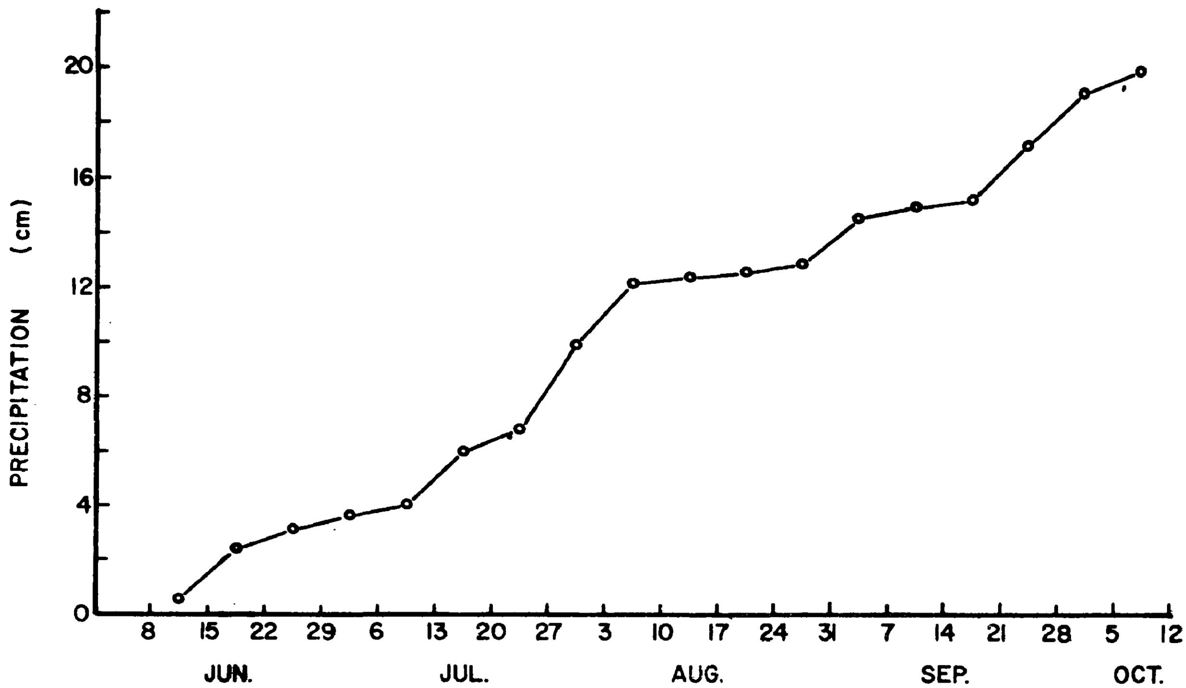
Cummulative Precipitation

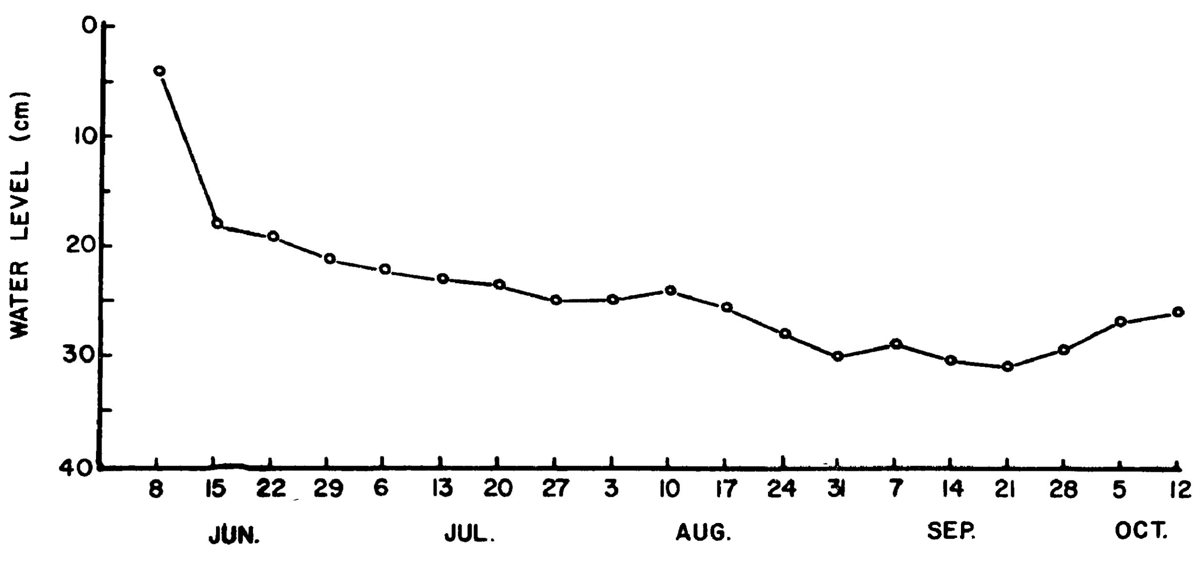
Summer, 1969

Figure No. 4

Water Level, Grassy Lake

Summer, 1969


PRECIPITATION (cm)
0
4
8
12
16
20
8 15 22 29 6 13 20 27 3 10 17 24 31 7 14 21 28 5 12
JUN.
JUL.
AUG.
SEP.
OCT.


WATER LEVEL (cm)
0
10
20
30
40
8 15 22 29 6 13 20 27 3 10 17 24 31 7 14 21 28 5 12
JUN.
JUL.
AUG.
SEP.
OCT.

A comparison of Figures 3 & 4 gives some indication of the variability of the effect of given amounts of precipitation on the water level of the lake.

PERIOD	PRECIPITATION (cm)	CHANGE WATER LEVEL (cm)
July 27 - Aug. 10.	5.28	+ 1.0
Aug. 31 - Sept. 7.	1.67	+ 1.0
Sept. 21 - Oct. 5.	3.85	+ 4.0

Water Currents:

There is no evidence of strong current flow at any point throughout Grassy Lake. The drainage pattern into the lake, with the exception of surface run-off resulting from melting of the snow cover as well as spring rainfall, consists of seepage of ground water, and takes place around the entire shoreline of the lake.

A very slight current exists during periods of high water level, in front of the outlet over the ancient beaver dam at the south corner of the lake.

The outflow of water at the south corner, although diminishing as the summer progressed, was continuous throughout the period of the study.

Surface currents, resulting from the action of the wind, are almost always present to a greater or lesser degree. It is felt that these currents play a significant role in the distribution of heat as well as dissolved and suspended materials throughout the lake waters.

Springs:

No evidence was found to support the existence of springs feeding the lake from below the surface.

Colour of Water:

The water of Grassy Lake is yellow-brown to dark brown in colour. Water samples show little evidence of heavy staining as a result of dissolved materials, and most of the colour is considered to be due to the presence of suspended materials.

The shallow nature of the lake, and the almost constant influence of the wind, have led to considerable turbidity. The bottom vegetation in the central portion of the lake is not recognizably visible, even at noon on a clear, calm day. Sufficient light reaches the substrate, however, to support a dense and continuous mat of submerged rooted vegetation.

Production of Methane:

The production of methane gas, in considerable quantity, was noted during the late spring and summer months. A constant flow of bubbles rising to the surface of the water was particularly noticeable during calm periods, especially during the evening hours.

Collections were made by driving a paddle into the bottom, thus releasing large quantities of the gas trapped in the substrate.

A detailed analysis of this gas was not possible at this time, but samples were ignited in air, and burned with the characteristic blue flame. The odour of the gas would seem to indicate the presence of hydrogen sulphide.

Hydrogen Ion Concentration:

A series of 26 readings was taken on July 29, 1969, by means of an E.I.L. Model 30C portable pH meter.

Eleven samples were taken from the surface waters of the lake, seven samples from the substrate along the northeast and southeast shore, two from the rock shelf at the southwest end of the lake, two samples from the vegetative mat at the northeast end, three samples from the sand-muck soils along the northwest and southwest shore, and one sample from the sand at the waterline on the southeast shore.

The following table gives the results of the sampling.

LOCATION	NO. of SAMPLES	RANGE	MEAN VALUE
Water Surface	11	7.75 - 8.10	7.84
Substrate	7	6.65 - 6.85	6.79
Vegetative Mat	2		5.90
Rock Shelf	2	-	8.35
Sand-Muck	3	6.50 - 6.70	6.60
Sand	1		7.50

The water of Grassy Lake, being only slightly basic in nature, can be generally considered as neutral as far as broad classification is concerned. The influence of the sedimentary limestones of the area on the pH of the water is illustrated by the 8.35 reading obtained when samples of the rock shelf at the southwest end were crushed and mixed with distilled water. Other evidence includes the deposits of calcium carbonate found on the submerged stems and leaves of *Potamogeton amplifolius*, and the presence of such species as *Chara* sp., and *Nitella* sp. (Reid 1961, Spence 1967).

Soils:

Considerable quantities of medium and fine grained sands are found in the vicinity of Grassy Lake. With the exception of the foot of the slope along the southeast shore which consists mostly of broken rock and coarse to fine gravels, and the shelf of sedimentary rock on the southwest shore of the lake, the remainder of the shoreline, both above and below the waterline, is dominated by sand.

Under the central portion of the lake, the sand is covered by a layer of dark brown to black ooze, and is also hidden by the mats of bog vegetation at the northeast end and the southwest corner. Along the northwest shore, the sand becomes exposed, to varying degrees, between water depths of 40 to 80 centimetres and the shore.

The grass-sedge mat surrounding the lake, between the boundary of the forested areas and the shoreline, and with the exception of the aforementioned rock and bog areas, is established on a sand base covered to various depths (0 to 25 centimetres) by a layer of black, semi-decomposed organic matter, originating with the plant and animal life of the terrestrial shore environment.

In December 1969, three sets of soil samples were taken from the bottom of the lake. These were obtained at 5 metre intervals, at points 15, 20, and 25 metres from the shore. The line of samples was in the vicinity of, and parallel to, the thermocouple standards.

The samples were obtained from the upper 10 centimetres of the substrate. These were air dried, and tests for "loss on ignition" (Atkinson, Giles, Maclean and Wright 1958), and water-retaining capacity (Curtis and Cottam 1962) were applied. The results of these tests are summarized in the tables below.

(a) Loss on Ignition:

	SAMPLE					
15 Metre Site	15-A	15-B	15-C	15-D	15-E	MEAN
Carbon Content (%)	4.59	4.81	4.92	5.06	4.35	4.75
Hydrogen Ion Conc.	6.4	6.4	6.4			6.4
20 Metre Site	20-A	20-B	20-C	20-D	20-E	MEAN
Carbon Content (%)	18.51	19.20	20.07	20.55	19.16	19.50
Hydrogen Ion Conc.	6.2	6.2	6.2			6.2
25 Metre Site	25-A	25-B	25-C	25-D	25-E	MEAN
Carbon Content (%)	10.86	12.28	11.82	13.89	11.52	12.07
Hydrogen Ion Conc.	6.4	6.3	6.3			6.3

(b) Water-Retaining Capacity:

	SAMPLE			
15 Metre Site	15-A	15-B	15-C	MEAN
Water-Retaining Capacity (%)	84.4	85.4	81.7	83.8
20 Metre Site	20-A	20-B	20-C	MEAN
Water-Retaining Capacity (%)	168.6	170.0	163.9	167.5
25 Metre Site	25-A	25-B	25-C	MEAN
Water-Retaining Capacity (%)	135.0	145.3	127.9	136.1

The reduced carbon content and the lower water-retaining capacity of the 15 metre site reflects the increasing amount of inorganic materials being mixed with the organic sediments as the shoreline of the lake is approached.

The greatest carbon content and water-retaining capacity was to be found at the 20 metre site. It would be in this area that the effects of wave action, reduced by increasing depth of water, would deposit the larger amounts of fine organic debris (Spence 1967).

The 25 metre site shows a slight reduction in both factors, reflecting a diminished influence of turbulence, and a possible increase in decomposition.

It is noteworthy that the bottom materials at the 20 and 25 metre sites, while appearing outwardly to be high in organic content, do in fact contain a high percentage of fine inorganic sediments. The sandy nature of much of the Grassy Lake basin, the cemented sandstone of the adjacent rock formations, the proximity of the partially paved highway with its considerable traffic load, and the almost constant presence of wind due to the position of the lake with respect to Lake Superior, would account for the influx of these fine materials. Wave action would then be responsible for much of the pattern of distribution.

<u>Temperature and Moisture Content of the Air:</u>

A thermo-hygrograph unit (Casella, London) was installed in a Fraser "Birdhouse" (Fraser 1961), on June 7th, 1969, approximately 20 metres from the shore in the vicinity of the thermocouple standards.

Continual records of air temperature and relative humidity were obtained for the period from June 8th to October 12th. The instrument was serviced at approximately 1100 hours on Sundays.

Calibration of the instrument was carried out every two weeks. A sling psychrometer (Casella, London) was used to calibrate the hair hygrometer, the range of error being $\pm$ 2.0%, and the mean error -0.19%. A standard laboratory mercury-in-glass thermometer was used to calibrate the bimetal temperature element, the range of error being $\pm$ 1.0 C^{o}, and the mean error 0.06 C^{o}.

A summary of the data obtained will be found in

Appendix C, sections (a) and (b). Figure No. 5 illustrates the weekly mean, mean high and mean low, and weekly high and low extremes of temperature. The data for relative humidity, in the form of weekly mean, mean high and mean low is illustrated in Figure No. 6.

The high and low extremes of air temperature are of particular interest from the point of view of their influence on the terrestrial and aquatic environment, and consequently upon the plant and animal communities contained therein (Daubenmire 1964).

Movement of Air:

The movement of the air over the surface of the lake, and the interaction with other factors, can have a profound effect on the aquatic environment. Wind is involved in wave action and the consequent mixing and distribution of water at various temperatures, often throughout the length and depth of the lake, and particularly in the spring and fall of the year. The action of wind and wave can influence the distribution of dissolved and suspended organic and inorganic materials, hence the colour and turbidity of the water, and subsequently the penetration of various wavelengths of the incoming radiation. The distribution of gases, such as oxygen and carbon dioxide, is assisted by the action of the wind (Geiger 1961, Ruttner 1963).

Figure No. 5

Weekly Air Temperatures

(Thermograph)

Summer, 1969

Figure No. 6

Relative Humidity, Weekly Means

(Hygrograph)

Summer, 1969

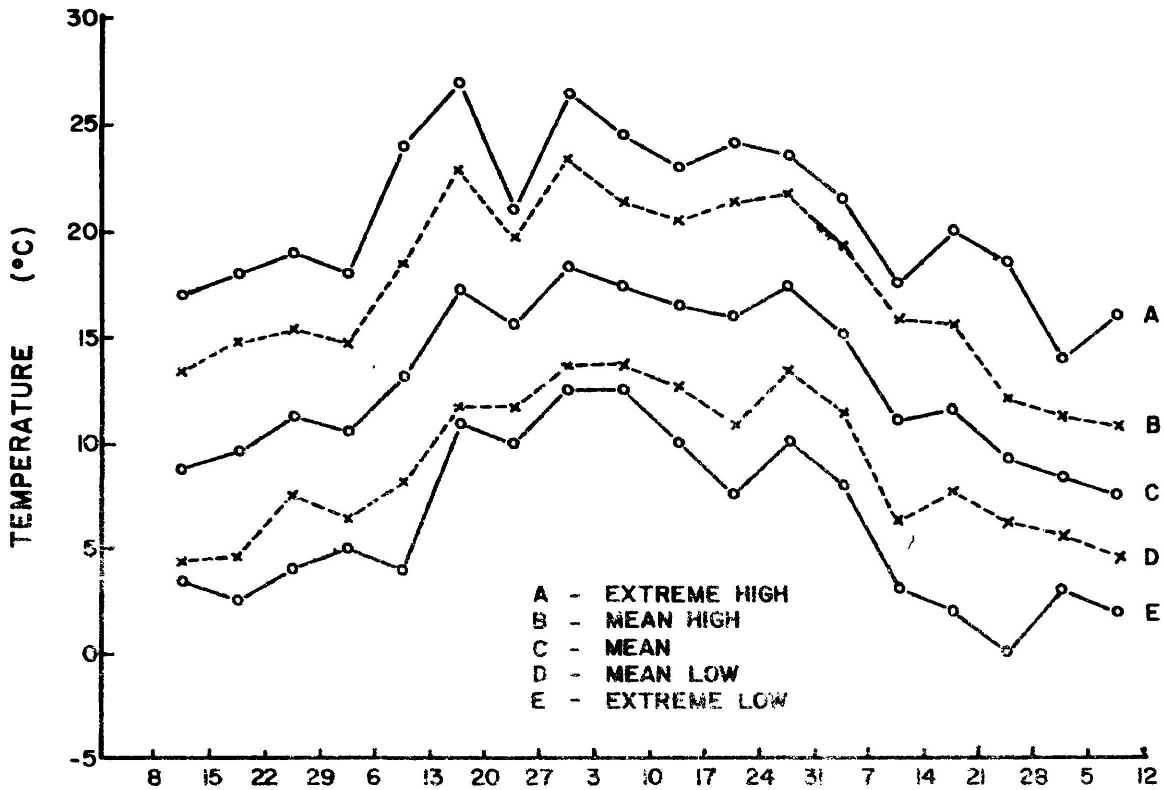


Figure No. 5

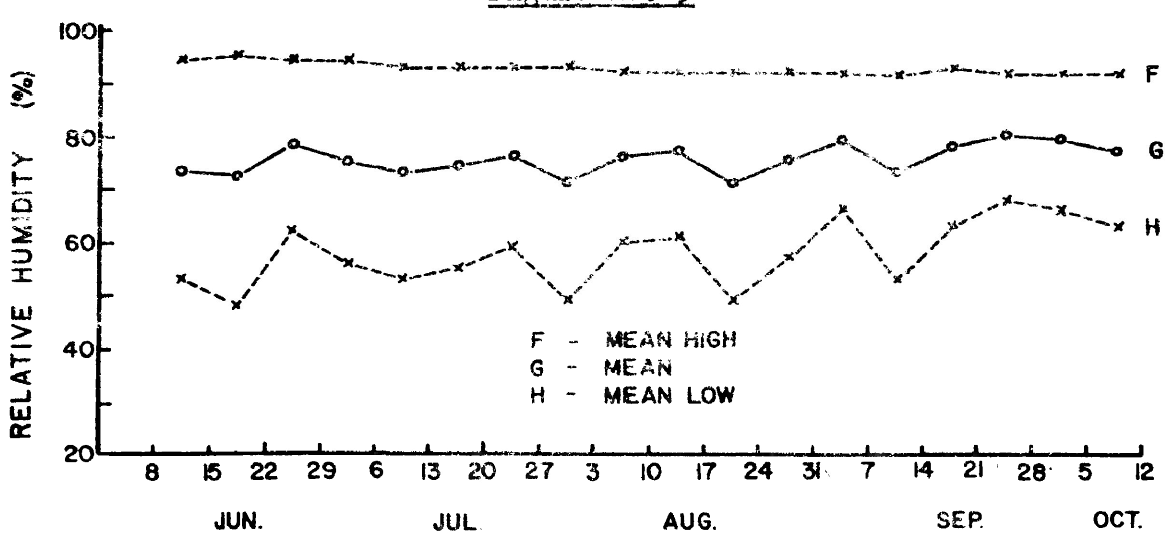


Figure No. 6

Wind and wave action are thought to be an important limiting factor in the survival of seedlings of Zizania aquatica, particularly during the floating leaf stage of development, and especially in those areas along the shoreline where little or no protection is offered to the young and weakly rooted plants by shoals, spits, or floating leaf macrophytes (Rogosin 1954).

To obtain a comparison of the movement of air over the surface of a small, inland lake, and that available on the shore of a large lake in the same vicinity, two Mk. II Sensitive anemometers (Casella, London) were employed.

Unit No. 1 was located approximately 50 centimetres to the southwest of thermocouple standard No. 1, in 100 centimetres of water, and so positioned that the head was 30 centimetres above the surface of the water. The battery operated counter unit was floated in a styrofoam tub, which in turn was anchored to the standard and a T-bar located nearby.

Unit No. 2 was installed at the highest point on an exposed hill, to the rear of the dock area at Silver Islet, and thus available to winds from the southeast, south, southwest, and west, moving over the surface of Lake Superior. The cups were situated 200 centimetres above the surface of the ground.

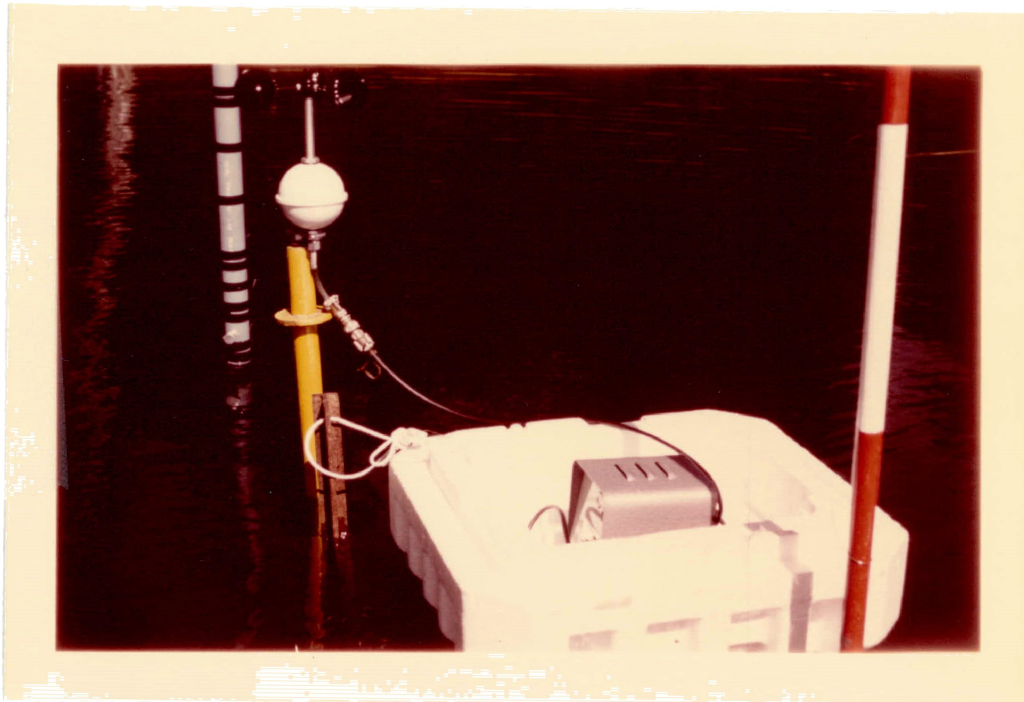
Readings were taken simultaneously at both sites at intervals of one hour over a three hour period, on three successive days.

Photograph No. 3

The Mk. II Sensitive anemometer installation, outside thermocouple standard No. 1 (TCS - 1). The mounting post, T-bar, and range pole are located in 1 metre of water. The counter unit will be seen floating in a styrofoam "tub".

Photograph No. 4

The leading edge of the semi-floating mat of vegetation, at the mid-point of the northeast end of Grassy Lake. This large portion of the mat is in the process of breaking away from the main body, and will eventually settle to the bottom, in about 1 metre of water.



During the period when the readings were underway, note was made of the effects of the various wind directions on the surface of Grassy Lake.

While the majority of air movement was from the south to southwest, some movement was experienced from the north, northwest, west, and southeast. A summary is found in the following table.

DATE	TIME	WIND DIR'N	WIND VEL. - M/SEC. Grassy Lake	Silver Islet
August 18	1000 hrs.			
		SW	1.9	2.7
	1100			
		SW	2.3	3.2
	1200			
		SSW	3.3	3.5
	1300			
August 19	1000 hrs.			
		NE	3.4	2.2
	1100			
		NE	3.1	2.6
	1200			
		SSW	2.2	2.7
	1300			
August 20	1300 hrs.			
		S	2.9	2.1
	1400			
		S	2.9	2.3
	1500			
		S	3.0	2.3
	1600			

On the dates indicated, Silver Islet received between 65% and 84% of the wind velocity recorded at Grassy Lake, when the wind was from the northeast, and between 73% and 79% when the wind swung over to the south.

Conversely, Grassy Lake received between 70% and 82% of the wind velocity recorded at Silver Islet, when the wind was from the southwest. During the period of readings, the increase in the velocity became apparent at Grassy Lake, as the direction of the wind swung from the southwest towards the south.

"Although hydrophytes vary in their ability to withstand the effects of wind and waves, few except the deeply submerged or firmly rooted can survive the complete absence of shelter. Hence the physiographic aspect of the shoreline is of primary importance (Sculthorpe 1967)."

A ridge of rock, approximately 60 metres in height, runs parallel to the northwest shore. Due to the fact, however, that this ridge is between 1/3 and 1/2 mile back from the shore of the lake, it offers no direct protection to the shoreline plant communities. The indirect influence is considerable, as the velocities of the winds from the north, northwest, and west are greatly reduced. This is particularly true in the case of the prevailing northwest winds. Consequently little wave action results, and the surface winds are gusty and multi-directional.

Although the ridge running parallel to the southeast shore is lower in overall height (25 metres), it rises directly from the edge of the water. As the ridge is also heavily wooded, it offers excellent protection from the east and southeast winds, as well as forcing winds from other directions upward before they reach the shore. There exists, therefore, a strip of relatively calm water, between 10 and 20 metres in width, and running along the entire southeast shore.

Wave action along the southeast shore would appear to be somewhat reduced as well. The topography is such that only winds from the west, northwest, and north could result in waves of any size, and the ridge system to the northwest of the lake successfully reduces this possibility. The presence along this shore of such species as Nuphar verigatum Engelm., Nuphar microphyllum (Pers.) Fern., Potamgeton natans L., Sparganium angustifolium Michx., and well developed plantations of Zizania aquatica, would seem to verify the fact that some protection is indeed available.

The northwest shoreline presents quite a different picture. With the absence of a distinct rise in ground from the shore, and a slight reduction in the density of the forest cover as the result of logging practices, winds from the northeast and south have free access to the area, and the resulting wave action is considerable. The gentle slope of the hard, packed bottom sand, which extends out from the shore between 10 and 15 metres to a water depth of approximately

80 centimetres, combined with the exposure of most of this shore to wave action, results in the absence of many of the shallow or weakly rooted hydrophytes, except where some protection is offered by dead-fall or small indentations in the shoreline. The inshore portions of the stands of wild rice at sites 9, 10, and 11 disappeared early in the floating leaf stage, the residual stands being confined to water depths of 30 centimetres or more. Only the strongly rhizomatous or securely rooted species such as _Eleocharis palustris_, _Equisetum fluviatile_, and _Carex lasiocarpus_ Ehrh. have become successfully established in the exposed areas.

The small bay at the south corner of the lake is protected from the action of the wind and waves by the slight headland on the southeast shore, the presence of a dense stand of tall trees growing almost to the water's edge, considerable dead-fall, and isolated islands of _Typha_ - _Iris_ - _Carex_ vegetation.

In the marsh area at the west corner, the outer face of the vegetative mat (_Typha_ - _Iris_ - _Scirpus_ - _Carex_) receives the full force of the wave action resulting from northeast winds. The leading edge of the mat presents a vertical face to a depth of between 80 and 120 centimetres. Little, if any submerged rooted vegetation is found at the foot of the face. Small patches of open but shallow water appear behind the outer rim of vegetation, and here are found such species as Sagittaria latifolia, Sparganium angustifolium, Nymphaea tetragona Georgi, Nuphar microphyllum, Potamogeton gramineus L., and Eutricularia vulgaris L. In this area as well, was found the finest stand of introduced wild rice.

The situation at the outer edge of the mat at the west corner is repeated at the northeast end of the lake. Here the full effect of wave action resulting from south and southwest winds is realized. At both sites, large pieces of the mat are breaking away (Photograph No. 4), assisted materially by the action of the waves. This continuous collapse could successfully prevent any advance of the mat over the lake waters, and smother attempts of vegetation to establish itself at the foot of the face.

It is therefore apparent that varying degrees of protection are required before many hydrophytes may become established.

BIOLOGICAL ASPECTS.

Vegetation:

The area surrounding the lake and making up the drainage basin, with the exception of the highway right-of-way and the open field at the north corner of the lake, is wooded. The dominant vegetation consists of a mature to overmature mixedwood stand of Populus tremuloides Michx., Populus balsamifera L., Betula papyrifera Marsh., Pinus strobus L., Pinus banksiana Lamb., Larix laricinia (Du Roi) K. Koch, Abies balsamea (L.) Mill., Thuja occidentalis L., Picea glauca (Moench) Voss, and Picea mariana (Mill.) BSP. An understorey of Abies balsamea, Picea glauca, Picea mariana, and Populus tremuloides is developing in the shade of the dominant species, and in the open areas around the lake.

An open grass-sedge mat surrounds the lake between the wooded area and the shoreline. The mat varies in width between 1 and 2 metres along the southeast shore, 8 to 18 metres along the northwest shore, to between 30 and 40 metres at the northeast and west ends of the lake. The grasses dominate that portion of the mat normally above the high water mark, while the sedges predominate in the area exposed by the drop in water level during the late spring and summer months.

The outer edges of the dense mats of floating and semi-floating vegetation at the northeast end and west corner of the lake, show no sign of advance into the water. The vegetation comes to an abrupt halt, and the face drops vertically to the surface of the bottom ooze, at a depth of approximately 1 metre. There is evidence that the edges of these mats are breaking away and falling into the water, often assisted by the weight of large animals such as the moose.

The emergent aquatic vegetation consists largely of Carex sp., Typha latifolia L., Iris versicolor L., Equisetum fluviatile L., Sagittaria latifolia Willd., Scirpus sp., and *Eleocharis* sp. Of these species, the *Carex* dominates most of the shoreline, with *Typha* assuming dominance in portions of the floating mats.

Floating leaf macrophytes are relatively scarce over the surface of the lake. Some *Nuphar varigatum* Engelm. is evident in the south and west corners, and in the sheltered portions of the southwest shore. *Nuphar microphyllum* (Pers.) Fern. is scattered thinnly along the east, southeast and southwest portions of the lake. *Potamogeton natans* L. appears in small patches along the east and southeast shore, with scattered individuals in the bay at the south corner, and along the southwest shore to the west corner. A single clone of *Potamogeton amplifolius* Tuckerm. is found in the centre of the lake, and consists of between 20 and 25 stems. Isolated patches of *Sparganium angustifolium* Michx. are found along the shoreline of the lake, and a few *Nymphaea tetragona* Georgi. in the west corner.

A dense mat of submerged rooted vegetation covers the bottom of the lake, thinning out as it approaches the shore, at a depth of between 40 and 50 centimetres. Included in this mat are such species as *Najas flexilis* (Willd.) Rostk. & Schmidt, *Potamogeton pectinatus* L., *Potamogeton filiformis* Pers., *Nitella* sp., and *Chara* sp. In the shallower, more protected waters near the shore are found such plants as *Scorpidium scorpioides* (Hedw.) Limpr., *Potamogeton gramineus*

L., *Utricularia vulgaris* L., *Sparganium angustifolium* Michx., and some *Chara* sp., and *Nitella* sp.

Aquatic vegetation is extremely scarce to non-existent in front of the unstable face of the floating and semi-floating mats, even at a depth of 1 metre.

No fish were found in Grassy Lake. Leeches were plentiful, but accurate identification was not possible at this time. The Molluscs included *Gyraulus* sp. and *Lymnaea* sp. Insects of the family Dytiscidae were represented by *Laccophilus* sp. and *Dytiscus* sp., and the family Notonectidae by *Notonecta* sp.

LIST OF PLANT SPECIES

The species of plants included in the following list were collected in the vicinity of Grassy Lake, during the late spring, summer, and early fall of 1969. They were taken from the substrate of the lake, the shoreline, and the grass-sedge mat, and approximately 2 metres into the forested area.

Determinations were checked by Claude E. Garton, Curator, C. E. Garton Herbarium, Lakehead University.

The phylogenetic order of families was based on the work of O. Lakela (1965). Conard (1956) was consulted on the mosses and liverworts, and Hale (1961) on the lichens. Other references used in the determination of species were: Fassett (1940), Gray (1950), Tryon (1954), Scoggan (1957), and Case (1964).

CLADONIACEAE

Cladonia rangiferina (L.) Web.

PARMELIACEAE

Parmelia spp.

PELTIGERACEAE

Peltigera apthosa (L.) Willd.

Peltigera canina (L.) Willd.

USNEACEAE

Alectoria americana Mot.

Alectoria nidulifera Norrl.

Evernia mesomorpha Nyl.

Usnea cavernosa Tuck.

Usnea longissima Ach.

SPHAGNACEAE

Sphagnum spp.

POLYTRICHACEAE

Polytrichum juniperinum Hedw.

AULACOMNIACEAE

Aulacomnium palustre (W. & M.) Schw.

MNIACEAE

Mnium affine Bland.

HYPNACEAE

Calliergon cordifolium (Hedw.) Kindb.

Callierogonella schreberi (Brid.) Grout

Scorpidium scorpioides (Hedw.) Limpr.

LESKEACEAE

Thuidium delicatulum (Hedw.) Mitt.

MARCHANTIACEAE

Marchantia polymorpha L.

EQUISETACEAE

Equisetum scirpoides Michx.

Equisetum fluviatile L.

Equisetum arvense L.

Equisetum silvaticum L.

LYCOPODIACEAE

Lycopodium Selago L.

Lycopodium annotinum L.

Lycopodium clavatum L.

Lycopodium obscurum L.

Lycopodium complanatum L.

OPHIOGLOSSACEAE

Botrychium virginianum (L.) Sw.

OSMUNDACEAE

Osmunda cinnamomea L.

POLYPODIACEAE

Athyrium thelypterioides (L.) Roth

Cystopteris fragilis (L.) Bernh.

Dryopteris cristata (L.) A. Gray

Polypodium virginianum L.

Thelypteris Phegopteris (L.) Slosson

PINACEAE

Abies balsamea (L.) Mill.

Larix laricinia (Du Roi) K. Koch

Picea glauca (Moench) Voss.

Picea mariana (Mill.) BSP.

Pinus banksiana Lamb.

Pinus strobus L.

Thuja occidentalis L.

TYPHACEAE

Typha latifolia L.

SPARGANIACEAE

Sparganium angustifolium Michx.

Sparganium chlorocarpum Rydb.

ZOSTERACEAE

Potamogeton natans L.

Potamogeton amplifolius Tuckerm.

Potamogeton pectinatus L.

Potamogeton filiformis Pers.

Potamogeton gramineus L.

Potamogeton Berchtoldi Fieber

NAJADACEAE

Najas flexilis (Willd.) Rostk. & Schmidt

ALISMATACEAE

Sagittaria latifolia Willd.

CYPERACEAE

Carex aquatilis Wahlenb.

Carex lasiocarpa Ehrh.

Carex crinata Lam.

Carex aurea Nutt.

Carex flava L.

Carex viridula Michx.

Carex Bebbii Olney

Eleocharis palustris L.

Eleocharis acicularis (L.) R. & S.

Eleocharis nitida Fern.

Scirpus hudsonianus (Michx.) Fern.

Scirpus validus Vahl

Scirpus cyperinus (L.) Kunth

GRAMINEAE

Agrostis scabra Willd.

Calamogrostis canadensis (Michx.) Beauv.

Calamogrostis inexpansa Gray

Phleum pratense L.

Zizania aquatica L.

JUNCACEAE

Juncus alpinus Vill.

Juncus nodosus L.

Juncus Dudleyi Weigand

Juncus tenuis G.B.

Juncus brevicaudatus (Engelm.) Fernald

LILIACEAE

Clintonia borealis (Ait.) Raf.

Maianthemum canadense Desf.

IRIDACEAE

Iris versicolor L.

Sisyrinchium montanum Greene

ORCHIDACEAE

Corallorhiza maculata Raf.

Goodyera repens (L.) R. Br.

Habenaria hyperborea (L.) R. Br.

Habenaria orbiculata (Pursh)

Habenaria obtusata (Banks) Richards

Listera cordata (L.) R. Br.

Malaxis paludosa (L.) Sw.

Spiranthes Romanzoffiana Cham.

SALICACEAE

Populus tremuloides Michx.

Populus balsamifera L.

Salix candida Fluegge

BETULACEAE

Alnus crispa (Ait.) Pursh

Alnus rugosa (Du Roi) Spreng.

Betula papyrifera Marsh.

POLYGONACEAE

Polygonum lapathifolium L.

NYMPHAEACEAE

Nuphar varigatum Engelm.

Nuphar microphyllum (Pers.) Fern.

Nuphar rubrodiscum Morong.

Nymphaea tetragona Georgi

CRUCIFERAE

Cardamine pensylvanica Muhl.

SARRACENIACEAE

Sarracenia purpurea L.

DROSERACEAE

Drosera rotundifolia L.

SAXIFRAGACEAE

Mitella nuda L.

Parnassia palustris L.

ROSACEAE

Fragaria vesca L.

Physocarpus opulifolius (L.) Maxim.

Potentilla norvegica L.

Potentilla palustris (L.) Scop.

Rubus pubescens Raf.

GUTTIFERAE

Hypericum virginicum L.

VIOLACEAE

Viola pallens (Banks) Brainerd

ONAGRACEAE

Epilobium angustifolium L.

CORNACEAE

Cornus canadensis L.

Cornus stolonifera Michx.

PYROLACEAE

Chimaphila umbellata (L.) Bart.

Moneses uniflora (L.) Gray

Pyrola secunda L.

Pyrola elliptica Nutt.

Pyrola asarifolia Michx.

ERICACEAE

Andromeda glaucophylla Link.

Chamaedaphne calyculata (L.) Moench

Gaultheria procumbens L.

Gaultheria hispidula (L.) Bigel

Kalmia polifolia Wang.

Ledum groenlandicum L.

Vaccinium angustifolium Ait.

Vaccinium oxycoccos L.

Vaccinium Vitis-idaea L.

PRIMULACEAE

Lysimachia terrestris (L.) BSP.

Lysimachia ciliata L.

Primula mistassinica Michx.

Trientalis borealis Raf.

GENTIANACEAE

Gentiana Andrewsii Griseb.

Halenia deflexa (Sw.) Griseb.

Menyanthes trifoliata L.

LABIATAE

Galeopsis Tetrahit L.

Lycopus uniflorus Michx.

Mentha arvensis L.

Scutellaria epilobiifolia Hamilt.

SCROPHULARIACEAE

Melampyrum lineare Desr.

Veronica scutellata L.

LENTIBULARIACEAE

Utricularia vulgaris L.

RUBIACEAE

Galium boreale L.

Galium triflorum Michx.

CAPRIFOLIACEAE

Diervilla Lonicera Mill.

Linnaea borealis L.

CAMPANULACEAE

Campanula aparinoides Pursh

Campanula uliginosa Rydb.

Lobelia Kalmii L.

COMPOSITAE

Achillea lanulosa Nutt.

Achillea millefolium L.

Anaphalis margaritacea (L.) C.B.

Aster macrophyllus L.

Bidens cernua L.

Circium arvense (L.) Scop.

Petasites palmatus (Ait.) Gray

Solidago canadensis L.

Taraxacum officinale Weber

LINE TRANSECT.

A line transect (Phillips 1959) was run parallel to, and 50 centimetres to the southwest of, the line of thermocouple standards established at right angles to the shoreline on the northwest shore of Grassy Lake. The transect was 17 metres in length, and included all the major species of plants encountered between the grass-forest boundary and the submerged, rooted aquatic vegetation in the vicinity of thermocouple standard No. 1, at a depth of 100 centimetres.

Figure No. 7 illustrates the distribution of species along the line of the survey. A sharp change in vegetative types will be noted at 5.3 metres, where the grass community suddenly gives way to a sedge community rooted in the saturated soil of the shoreline.

While thermocouple standard No. 3 was established at the edge of the water, at 4.5 metres, the transect was offset in order to avoid ground previously disturbed when the thermocouple cables were buried. This position carries the line over a small projection in the shoreline consolidated by the root system of a dead tree. The higher level of the terrain, therefore, continues to 5.3 metres, where it drops vertically a distance of 15 centimetres to the gently sloping ground at the waters edge.

This sudden drop is the exception rather than the rule, as the majority of the northwest shore presents a gentle slope from the edge of the forested area to a water depth of approximately 80 centimetres. At this point the hard sand bottom dips more sharply, the smooth contour of the substrate being maintained by a thickening deposit of ooze, which levels off at a depth of between 100 and 120 centimetres.

The northwest shore of the lake, the site of the transect, receives the full benefit of the incoming solar radiation during the greater portion of the day. The dense border of shrub species forms a backdrop for the grass-sedge mat, and assists in reducing the force of the wind.

The open mat is dominated by *Calamagrostis canadensis* (Michx.) Beauv. The soil is basically sand, overlain by approximately 5 centimetres of black, partially decomposed, organic matter. The slope from the edge of the forest to the shoreline is gentle, dropping only about 15 centimetres in 5 metres. Sufficient soil moisture would appear to have been available at all times, and no evidence of plant deterioration was noticed, even during periods of low lake level, warm air temperatures, clear days, and moderate to strong winds.

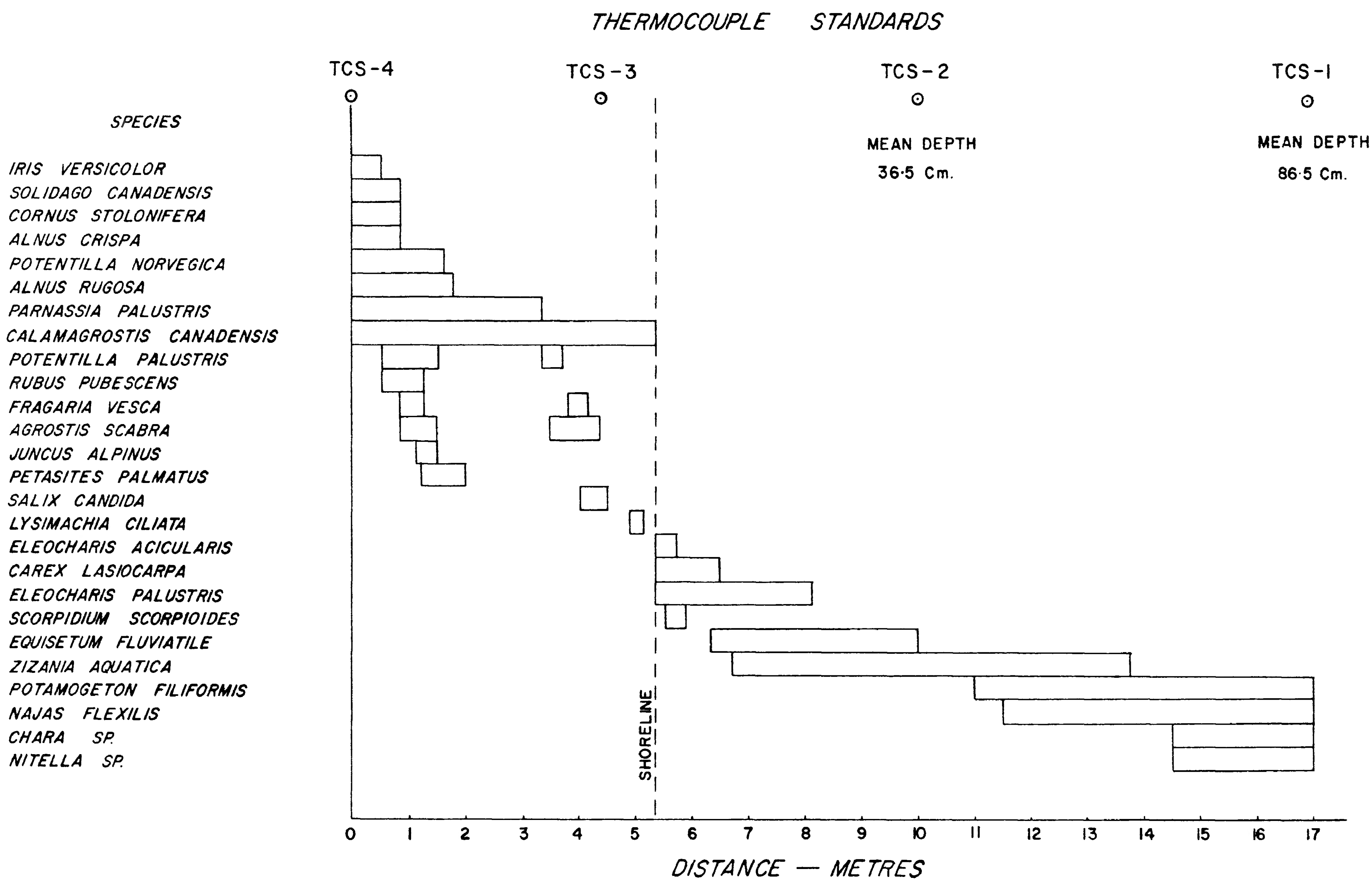
The boundary between the terrestrial and aquatic communities, as illustrated in Figure No. 7, would appear to be abrupt. As mentioned earlier in this section, this is not altogether typical of this shore, and various degrees of blending do exist.

The northwest shore is exposed to the action of wind and wave, and with the gentle slope of the littoral shelf, the shifting and sorting of substrate materials takes place. The often exclusive presence of such species as *Equisetum fluviatile* and *Eleocharis palustris* will attest to this fact. As the water deepens, the effects of wave action are reduced and the soils as a result of elutriation, become finer with a greater proportion of organic material. Such species as *Najas flexilis*, *Potamogeton filiformis*, *Chara* sp., and *Nitella* sp., are able to become established (Reid 1961, Sculthorpe 1967, Spence 1967).

Figure No. 7

Line Transcet - Presence

Summer, 1969


THERMOCOUPLE STANDARDS
TCS-4
TCS-3
TCS-2
TCS-1
MEAN DEPTH
36·5 Cm.
MEAN DEPTH
86·5 Cm.
SPECIES
IRIS VERSICOLOR
SOLIDAGO CANADENSIS
CORNUS STOLONIFERA
ALNUS CRISPA
POTENTILLA NORVEGICA
ALNUS RUGOSA
PARNASSIA PALUSTRIS
CALAMAGROSTIS CANADENSIS
POTENTILLA PALUSTRIS
RUBUS PUBESCENS
FRAGARIA VESCA
AGROSTIS SCABRA
JUNCUS ALPINUS
PETASITES PALMATUS
SALIX CANDIDA
LYSIMACHIA CILIATA
ELEOCHARIS ACICULARIS
CAREX LASIOCARPA
ELEOCHARIS PALUSTRIS
SCORPIDIUM SCORPIOIDES
EQUISETUM FLUVIATILE
ZIZANIA AQUATICA
POTAMOGETON FILIFORMIS
NAJAS FLEXILIS
CHARA SP.
NITELLA SP.
SHORELINE
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
DISTANCE — METRES

CHAPTER III

THE TEMPERATURE FACTOR

THE TEMPERATURE FACTOR

INTRODUCTION

"From the broad and basically ecological point of view the thermal properties of water and the attending relationships are doubtless the most important factors in maintaining the fitness of water as an environment" (Reid 1961).

Thus the temperature factor was considered of prime importance, and an understanding of the temperature relationships existent in the environment as basic to all further research.

That portion of the incoming radiation that is absorbed in the water is responsible for the production of heat energy, considered by Reid (1961) to be the most important regulator of living processes. Temperature relations control stratification, currents, distribution of organic and inorganic dissolved and suspended materials, turbidity, and changes in the density of water by both chemical and physical means.

Solar radiation is the greatest source of heat, as a result of absorbtion. Some heat is available, to a lesser degree, from the air and from the substrate. Under some conditions, condensation of water vapour may prove a source of heat. The majority of heat lost is through radiation, with some loss through evaporation and conduction to the air and the substrate (Ruttner 1963).

While the wind in considered to be the factor most responsible for the distribution of heat energy within the lake, change in density of the water plays an important role (Geiger 1961, Moss 1969).

Ruttner (1963) states that "We can, therefore, designate the thermal relations as the pivotal point of every limnological investigation".

While much data has been published on temperature relationships in larger bodies of water, small, and/or shallow ponds and lakes have been treated less extensively.

Moss (1969), in his work on Abbot's Pond, Somersetshire, has done an excellent study on chemical and thermal stratification in a shallow, sheltered pond. He found diurnal stratification that persisted for extended periods, so that this body of water displayed many features characteristic of larger and deeper bodies.

Miller and Rabe (1969), in comparing two Idaho reservoirs 200 and 32 acres in size, and 30 and 27 metres in depth respectively, found no evidence of a thermocline although temperature gradients were present. They have stated that they believe the wind to be a major factor involved in the mixing of the waters, although this was greatly assisted in their case by the fact that both reservoirs were drained from beneath, where the hypolimnion might have existed.

Eriksen (1966) concludes that many shallow bodies of water exhibit daily stratification, illustrative of the seasonal cycles of larger temperate lakes, in a single 24 hour period. Both ponds studied by Eriksen were small, 14 by 20 metres, and less than 40 centimetres in depth. Both were sheltered from the wind.

Eriksen notes, however, that of ten ponds studied by him over a period of a few years, only in the largest, designated a "lake", was stratification uncommon. This water was 1 metre in depth.

The extreme degree of turbidity in the two puddles mentioned in this paper is considered by Eriksen (1966) to be responsible for the exaggerated stratification, with 9 to 16C^{o} temperature differences. The absorbtion of heat in the upper layers of the water only, resulting in a considerable density gradient, lead to stable layering.

Hutchinson (1957), although dealing with the larger bodies of water in greater detail, has proven an excellent basic reference. Geiger (1961) devotes a portion of his work to a discussion of the temperature relations in small bodies of water, and to the air layer above them. Odum (1959) and Reid (1961) were consulted in the early stages of preparation for the present study, while Ruttner (1963) was used as a basic reference in all phases of the work.

Figure No. 8

GRASSY LAKE

Location of

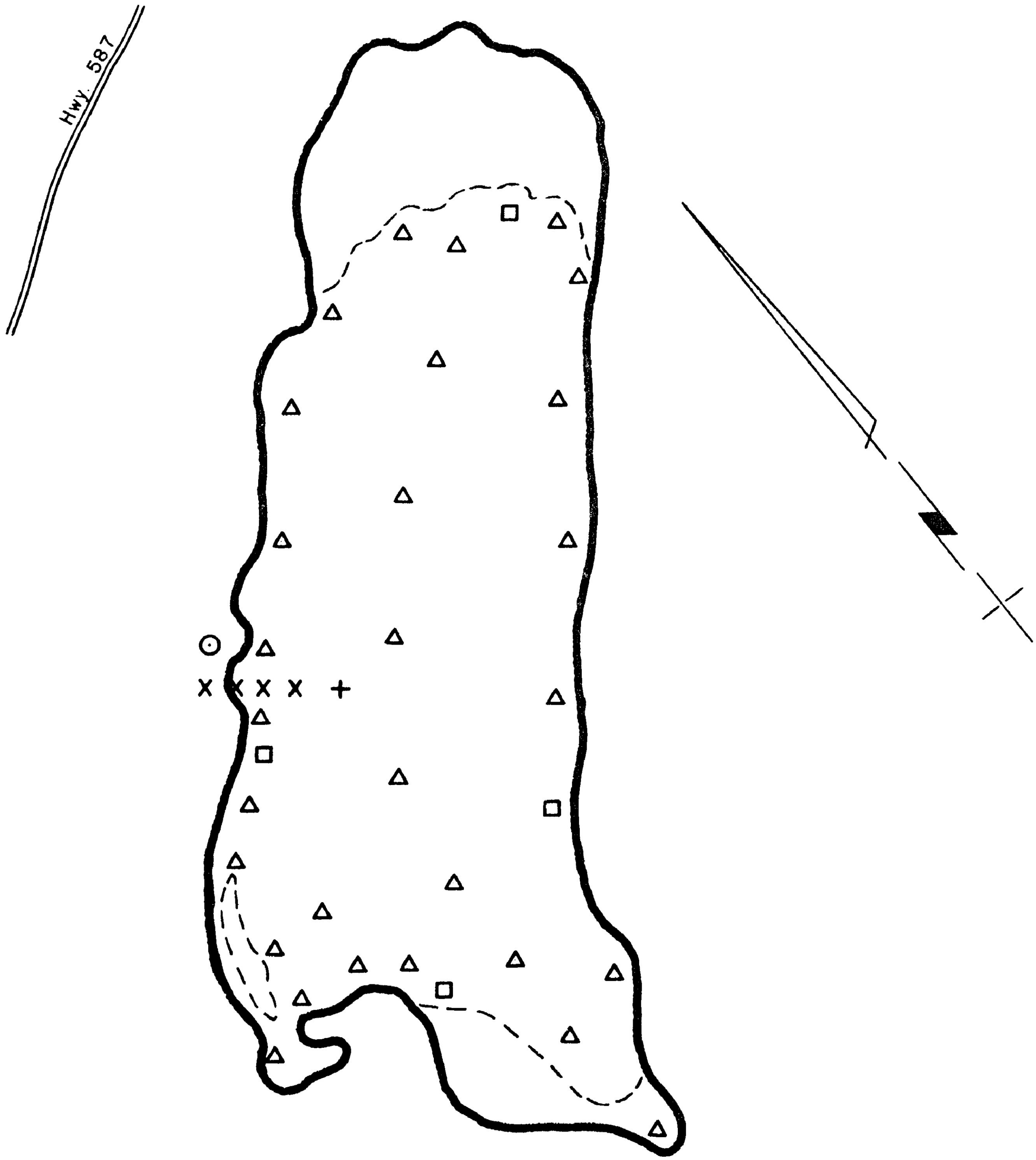
Thermocouple Standards

Temperature Probe Readings

Hygrothermograph

Floating Maximum-Minimum Thermometers

Anemometer



GRASSY LAKE

THERMOCOUPLE STANDARDS X

FLOATING MAX.—MIN. THERMOMETERS □

HYGROTHERMOGRAPH ⊙

SENSITIVE ANEMOMETER +

TEMPERATURE PROBE △

SCALE: I Centimetre = 25 Metres

THE TEMPERATURE FACTOR

I - THERMOCOUPLES

Methods:

A three dimensional picture of the distribution of heat in the various layers of air, water, and soil surrounding the individual boundaries between media, is essential to the overall understanding of the movement of heat energy throughout, as well as, in and out of the ecosystem.

The general shoreline area includes both the terrestrial and aquatic habitats, and each of these basic environments has a direct or indirect influence upon the other.

Temperature sensitive elements were established at set intervals in all three media. Vertical and horizontal temperature gradients could thus be determined, and data on the weekly and diurnal movement of heat energy obtained.

The thermocouple elements were established in a line transecting the shoreline environment, and including the terrestrial and aquatic habitats, as well as the "intermediate" zone of the shoreline itself.

A series of 4 standards, containing 55 thermocouple elements, was established in a line at right angles to the mid-point of the northwest shore of Grassy Lake, over a distance of 17 metres, between a water depth of 1 metre and the grass-forest boundary.

The thermocouple elements were constructed of No. 26 copper - constantan, single polyvinylchloride covered wire. The sensing elements were cleaned, twisted together, and soldered. Each element was then checked for continuity, and coated with a flexible plastic cement for added protection. The elements were then mounted on lengths of 4.5 centimetres (1.75") I.D., 0.65 centimetres (0.25") wall, heavy-duty plastic laboratory tubing. Those elements exposed in the air, as well as those located at the air-water and air-soil interface and 2.5 centimetres below the interface, were so affixed that they extended a minimum of 11 centimetres from the face of the tubing. The remainder of the elements, from the 10 centimetre mark below the interface and down, were secured close to the face of the tubing, but insulated from the tubing by a 1.3 centimetre (0.5") square of styrofoam, 0.65 centimetres (0.25") in thickness.

For purposes of uniform shading, all sensing elements were located on the same side of the tubing.

The copper - constantan pairs were led to a point on the standard where they could most conveniently be formed into a single cable, wrapped completely in black plastic tape, and buried in the soil to the potentiometer site where the readings were taken.

Figure No. 9 illustrates the arrangement of the thermocouple elements on each of the four standards, and indicates the corresponding reference code number.

At the recording site, approximately 13 metres back from the shoreline, the cables were broken, and the individual pairs split back for a distance of 1 metre. The constantan members from each cable were stripped, cleaned, wrapped, and soldered to a single piece of No. 16 soft copper wire, all connections checked for continuity, and the junction insulated by means of black plastic tape. The four junctions were then bound together for simultaneous insertion in the ice-water bath.

The single copper lead from the junction, and the individual copper leads from each of the copper - constantan pairs, were soldered to an 18-position "female" Jones plug, making 4 plugs in all, one for each standard.

A small metal cabinet was fitted with the single "male" Jones plug, an 18-position, heavy-duty wafer switch, and two binding posts. Leads were taken from the binding posts to the portable Thermo Electric "Super Mite" potentiometer. (See photograph No. 5). This unit was designed to reduce, as far as possible, the time required for the readings.

Figure No. 10 illustrates the wiring diagram for the thermocouple assemblies.

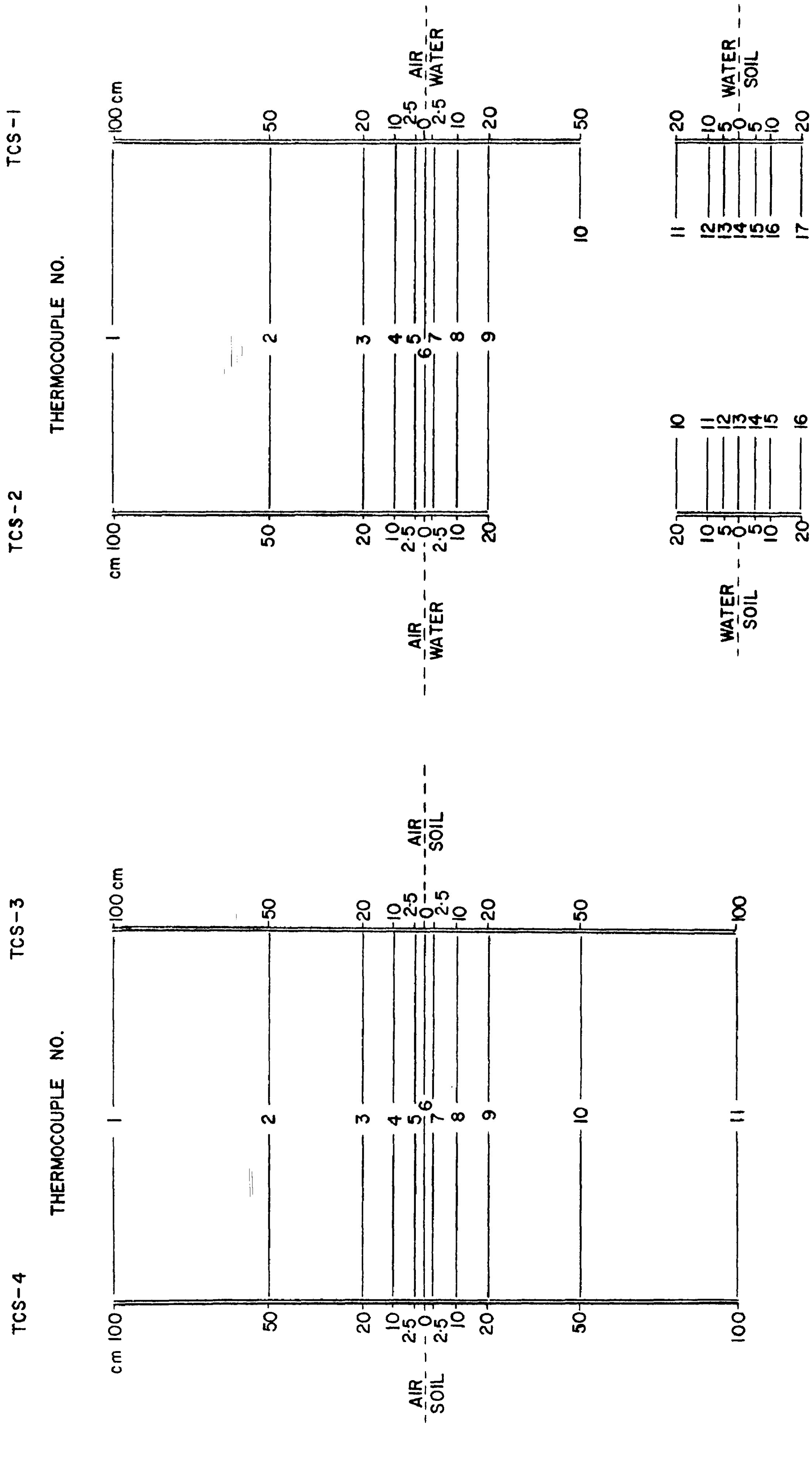
Thermocouple standard No. 1, (TCS-1), was mounted in two sections, on a single 2.5 centimetre (1") drill steel rod, driven into the substrate in 1 metre of water, at a distance of approximately 12 metres from the shore. The lower section contained elements for 20, 10 and 5 centimetres above and below the water-substrate interface, as well as an element at the interface itself. This section was pressed carefully into the soil, with special care taken to avoid any disturbance of the natural distribution of the bottom sediments in the vicinity of the standard. The upper section, containing elements for 100, 50, 20, 10, and 2.5 centimetre readings in air, one unit at the air-water interface, and elements for 2.5, 10, 20 and 50 centimetres below the surface of the water, was so designed as to permit adjustment with changes in the water level of the lake. The tubing could be secured at any designated level by means of a cadmium-coated lag screw. (Photograph No. 6, Figure No. 9-A)

The 30 centimetre break between elements No. 10 and 11 allowed for the adjustment of the upper section.

Thermocouple standard No. 2, (TCS-2), also designed in two sections, but mounted on separate lengths of drill steel located in close proximity, was essentially the same in design as TCS-1. This was established in 50 centimetres of water, approximately 4 metres from shore. The element found at the 50 centimetre mark below the surface on TCS-1, was eliminated in the case of TCS-2. The lag screw was again used to secure the upper section, and the twin post design permitted the same degree of adjustment as found in TCS-1.

Figure No. 9

Location of sensing elements on thermocouple standards, with the corresponding code numbers.



TCS-1
TCS-2
THERMOCOUPLE NO.
AIR
WATER
SOIL
100 cm
cm 100
TCS-3
TCS-4
THERMOCOUPLE NO.
AIR
SOIL
100 cm
cm 100

Figure No. 9-A

Location of the thermocouple elements on standard - TCS-1. Illustrating break in tubing and drill steel mounting rod.

T. C. STD. No. 1

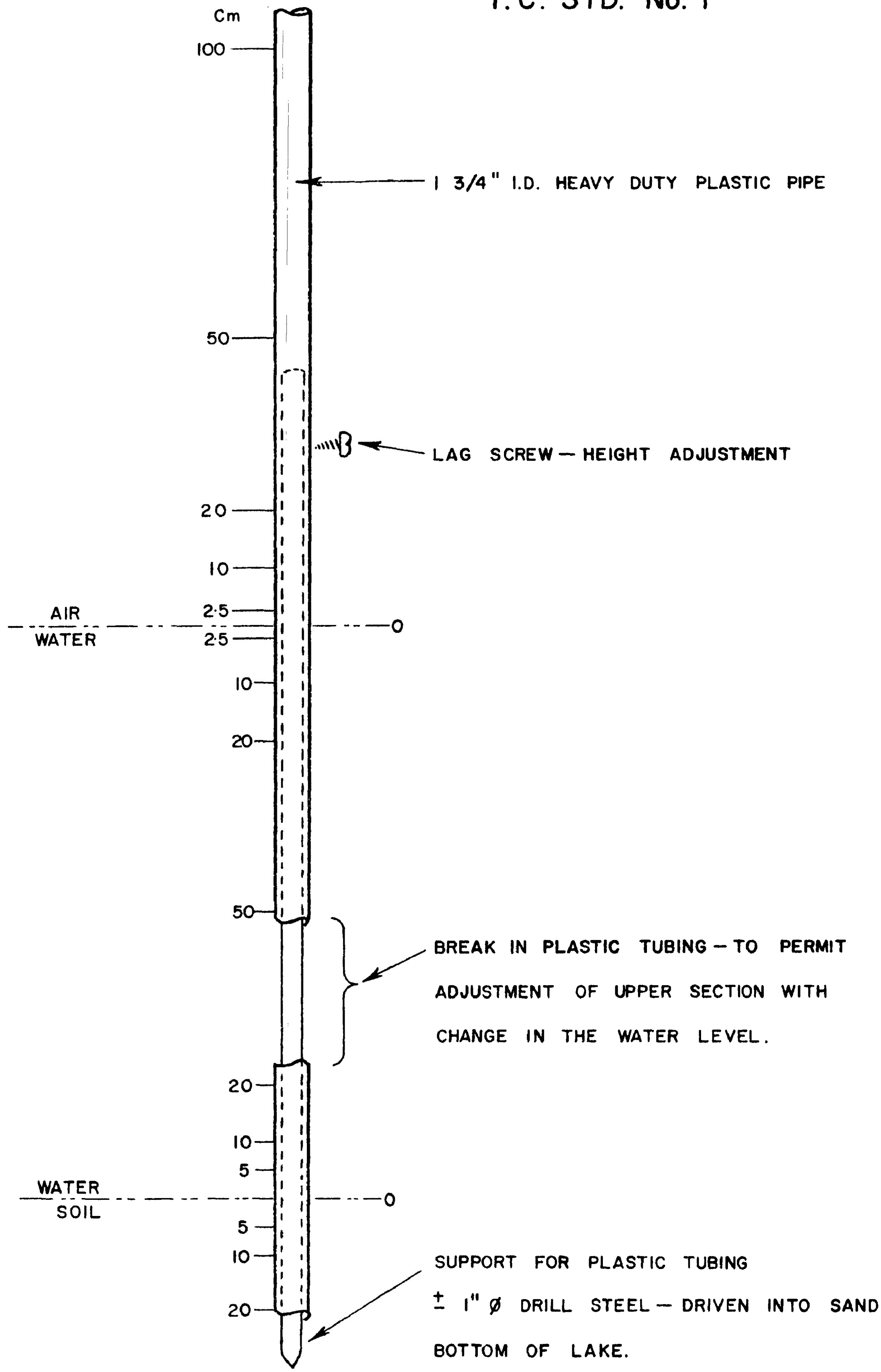
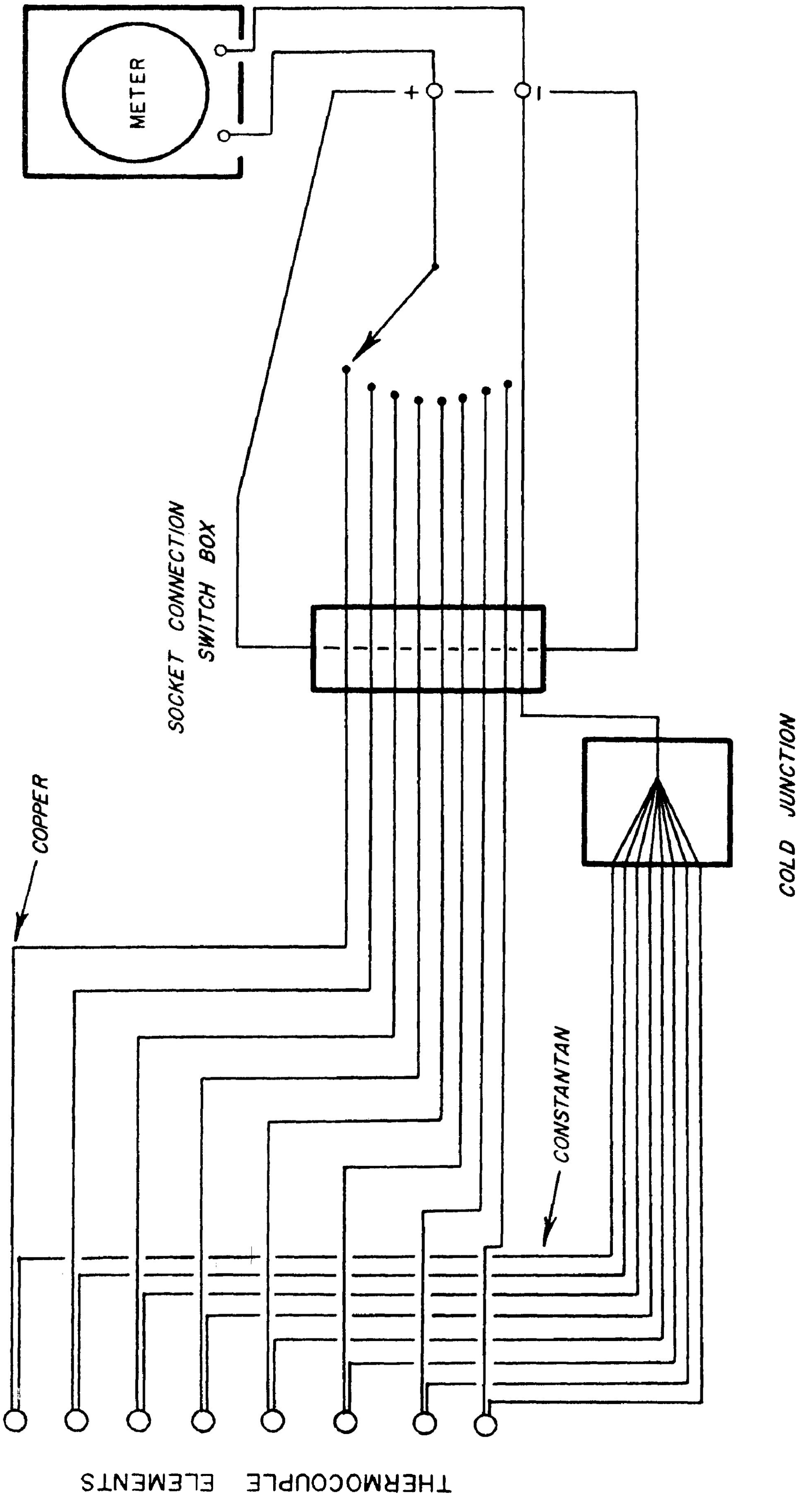

Cm
100
1 3/4" I.D. HEAVY DUTY PLASTIC PIPE
50
LAG SCREW — HEIGHT ADJUSTMENT
20
10
2.5
AIR
WATER
0
2.5
10
20
50
BREAK IN PLASTIC TUBING — TO PERMIT ADJUSTMENT OF UPPER SECTION WITH CHANGE IN THE WATER LEVEL.
20
10
5
WATER
SOIL
0
5
10
20
SUPPORT FOR PLASTIC TUBING
± 1" Ø DRILL STEEL — DRIVEN INTO SAND BOTTOM OF LAKE.

Figure No. 10

Wiring Diagram

Thermocouple Assemby

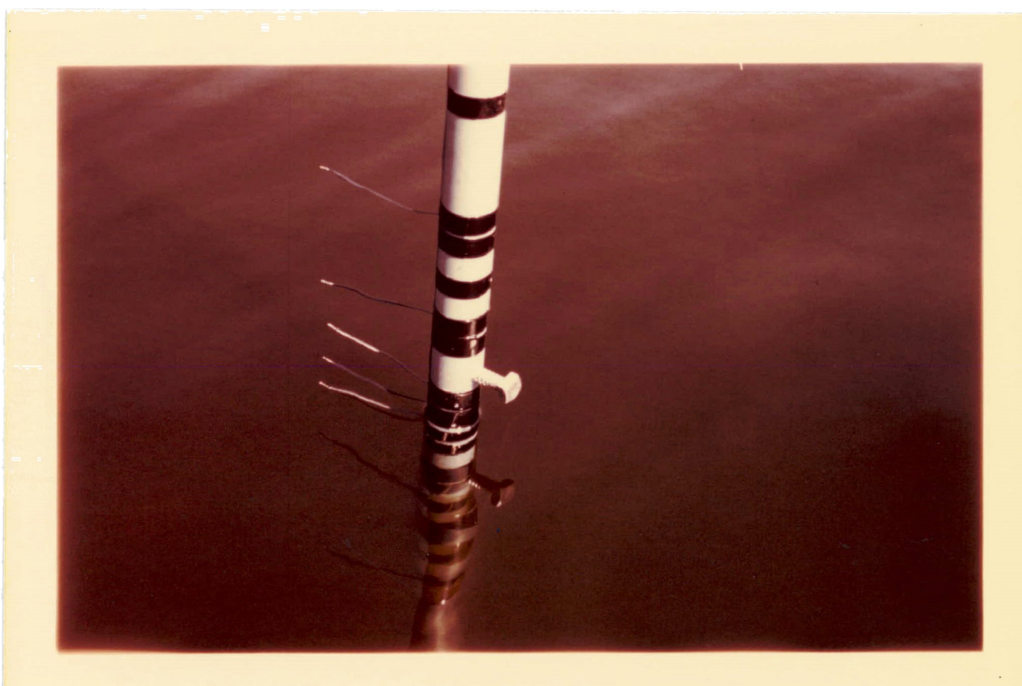

METER
SOCKET CONNECTION
SWITCH BOX
COPPER
CONSTANTAN
COLD JUNCTION
THERMOCOUPLE ELEMENTS

Photograph No. 5

Equipment assembled at the potentiometer site, including the Thermo Electric "Super Mite" potentiometer, switch box, 4 Jones plugs attached to the cable from each thermocouple standard, and the Thermos flask used as a reference junction. The 4 junctions, one on each cable, are seen installed in the ice-water bath.

Photograph No. 6

Thermocouple standard No. 1 (TCS-1). This photograph illustrates the extension of the sensing elements, including the 2.5 centimetre element below the interface, visible in the picture. The lag screw for holding the adjustment can be seen on the back of the blue plastic tubing.



Thermocouple standard No. 3, (TCS-3), was pressed into the soil at the edge of the water. This standard contained elements 100, 50, 20, 10, and 2.5 centimetres above and below the air-soil interface, and a single element at the interface itself. (Photograph No. 7).

Thermocouple standard No. 4, (TCS-4), an exact duplicate of TCS-3, was pressed into the soil at the grass-forest boundary, at a point approximately 5 metres back from the shoreline.

Figure No. 11 shows the location of the thermocouple standards, with respect to each other, and to the shoreline.

All sensing elements and the calibrating thermometers were shaded from direct solar radiation. While the plastic tubing offered some shade, additional protection in the form of long cardboard strips, 11.5 centimetres in width, were mounted on the standards on the side opposite to that occupied by the sensing elements. (Photograph No. 8). Shade was thus guaranteed for all extended elements, including those 2.5 centimetres below the interface.

The reference junction consisted of a Thermos flask filled with crushed ice and water. This was installed at least 1 hour before the readings were to be taken. A mercury-in-glass laboratory thermometer was used to check the temperature of the reference junction, which remained at $0^{o}C$.

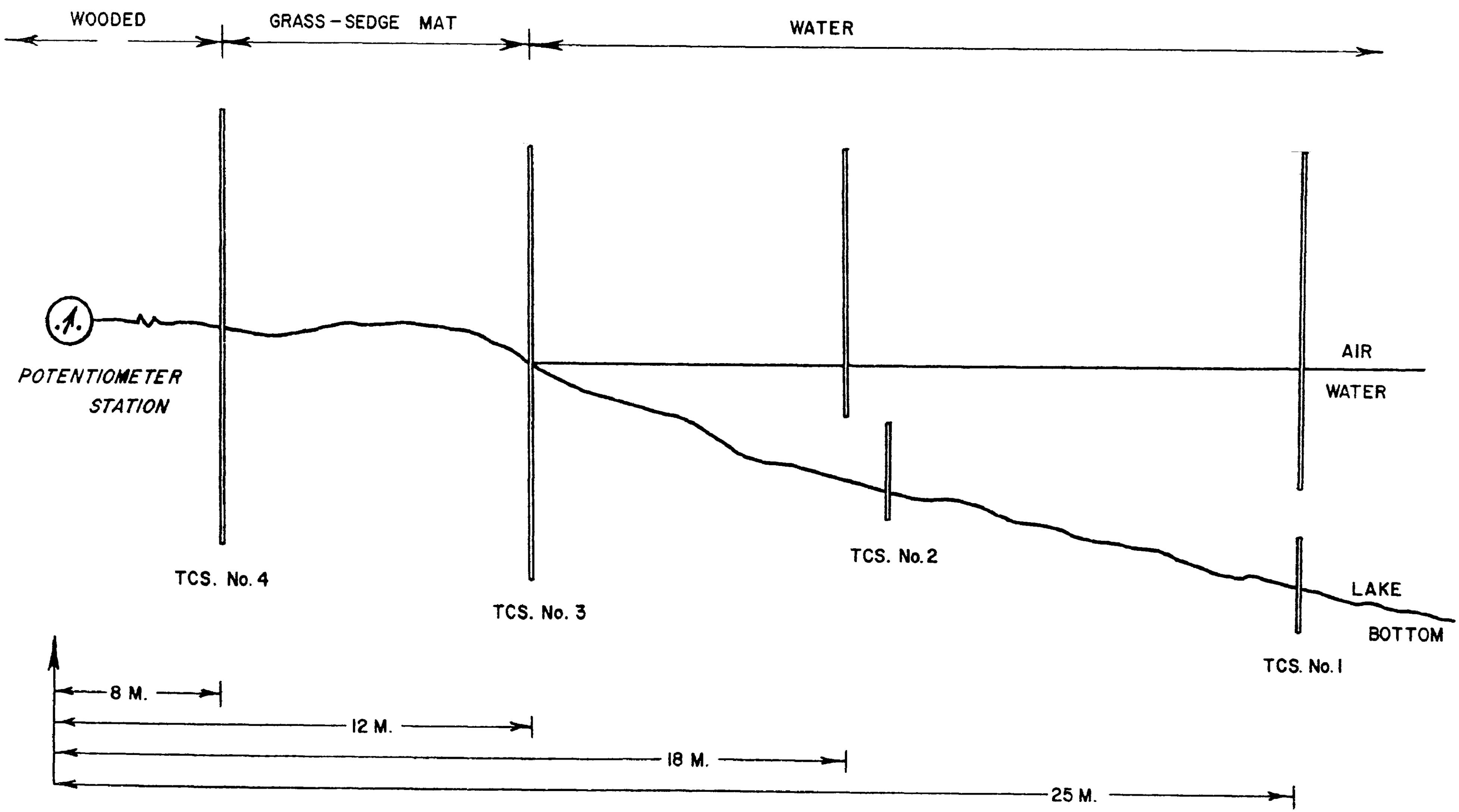
Two distinct series of readings were taken by means

Figure No. 11

Grassy Lake

Layout of Thermocouple Standards.

LAYOUT OF THERMOCOUPLE STANDARDS-GRASSY LAKE



Photograph No. 7

Looking northeast from behind thermocouple standard No. 3, (TCS-3), installed at the edge of the water, on the northwest shore. The black muck of the shoreline, and the saturated nature of the soil, is visible at the bottom of the standard.

Photograph No. 8

View southeast across Grassy Lake, approximately 150 metres, from the thermocouple site at the mid-point on the northwest shore. TCS-1 can be seen in the centre of the picture, furthest from the shore. TCS-2 next, and TCS-3 in the foreground at the left, located at the shore of the lake. The cardboard shields are in place on the standards, for the provision of extra shading.

of the thermocouple assembly, a total of 1760 readings over the period of study.

Series A:

A series of 880 readings, 55 readings per week for the 16 week period between June 30th and October 12th. Readings were made at 1200 hours on Sunday, (with the exception of June 30th), and occupied a period of between 12 and 15 minutes.

Readings commenced below the ground at TCS-4, taking the standards in reverse order, and finishing with the 100 centimetre in air element at TCS-1.

Upon completion of the readings, the below ground readings at TCS-4 were repeated, as a check on the reference junction (Barclay-Estrup 1966).

Calibration checks were carried out weekly, by means of a mercury-in-glass laboratory thermometer installed between elements No. 6 and 7 at TCS-3. Care was taken to insure, as far as possible, that the calibration thermometer did not interfere with the readings of the elements.

A summary of data obtained in the Series A readings, will be found in Appendix D.

Series B:

A series of 880 readings, 55 readings each at 3 hour intervals over a period of 48 hours, were taken from

0900 hours on August 11th to 0600 hours on August 13th.

The time required to carry out the individual sets of readings, the order in which the readings were taken, the reference junction and calibration checks, are similar to those in Series A.

A summary of data obtained in the Series B readings, will be found in Appendix G.

Almost all readings in Series A were obtained under clear or only partially cloudy skies, and the shades were in place at the time of all readings, for purposes of uniformity.

In Series B, readings from 0900 hours on August 11th up to and including 0900 hours on August 12th, were taken under clear skies. Light winds only were present from 0900 hours to 1800 hours on August 11th, and no noticeable air movement from 2100 hours on August 11th to 0600 hours on August 12th. Complete cloud cover formed between 0900 hours and 1200 hours on August 12th, and persisted, with intermittent light rain and little movement of air, until the 0600 reading on August 13th.

Certain considerations must be taken into account with regard to the data obtained at the "interface". It is not possible to obtain a reliable reading in the exact plane of the interface, and the results will show the predominant influence of one or the other of the media involved. Before the readings commenced, a decision had to be made with regard to the placement of the elements, and as a result, those situated at the air-water interface were located in the top 2 millimetres of the water, and those at the air-soil interface were placed in the top 2 millimetres of the soil. Those at the water-substrate interface were adjusted as carefully as possible under the circumstances, which included the location of the boundary in the extremely soft bottom ooze, particularly at TCS-1. The reduced thickness and the higher inorganic content of the ooze at TCS-2 made the more accurate placement of the elements possible.

Wave action may have had some influence on the readings taken at the interface, although observation showed that the 11 centimetre extension was sufficiently flexible to allow the surface tension of the water, in all but the highest waves, to retain the element while carrying it up and down.

Results:

Figure No. 12 summarizes the mean temperatures in air, water, and soil, by thermocouple standard, for the period of study.

The mean air temperatures over the water at TCS-1 and TCS-2 are quite similar, and remain between 16°C and 17°C from just above the air-water interface to a height of 1 metre. The mean air temperature at TCS-3 increases from 17.1°C at 100 centimetres above the interface, to 18.1°C at 2.5 centimetres above the interface. The mean air temperature at TCS-4 ranges from 18.4°C at 1 metre, to 22.8°C at 2.5 centimetres.

The mean water temperatures at TCS-1 and TCS-2 remain reasonably uniform from 10 centimetres below the air-water to 10 centimetres above the water-soil interface. Some degree of stratification is apparent in the 10 centimetre water layers at the top and bottom of the body of water. The change in temperature consists of a decrease with an increase in depth.

The break in the vertical axis (Distance) at TCS-1 and TCS-2 corresponds with the break in the tubing of the standards to permit adjustment of the upper section with changes in water level. As the level dropped, 27 centimetres by the week of September 14th, elements 10 and 11 at TCS-1 approached within a few centimetres of each other. While the same basic situation held for TCS-2, elements 9 and 10 actually passed each other due to the extensive drop in the lake level.

Mean surface temperatures increase, from 19.2°C at TCS-1, to 20.0°C at TCS-2, and 22.5°C at TCS-4. The mean surface temperature at TCS-3 is the exception, being the lowest of the four readings, or 18.0°C.

Figure No. 12

Vertical Profile - Mean Temperature.

Recorded at individual thermocouple standards, TCS-1, TCS-2, TCS-3, and TCS-4.

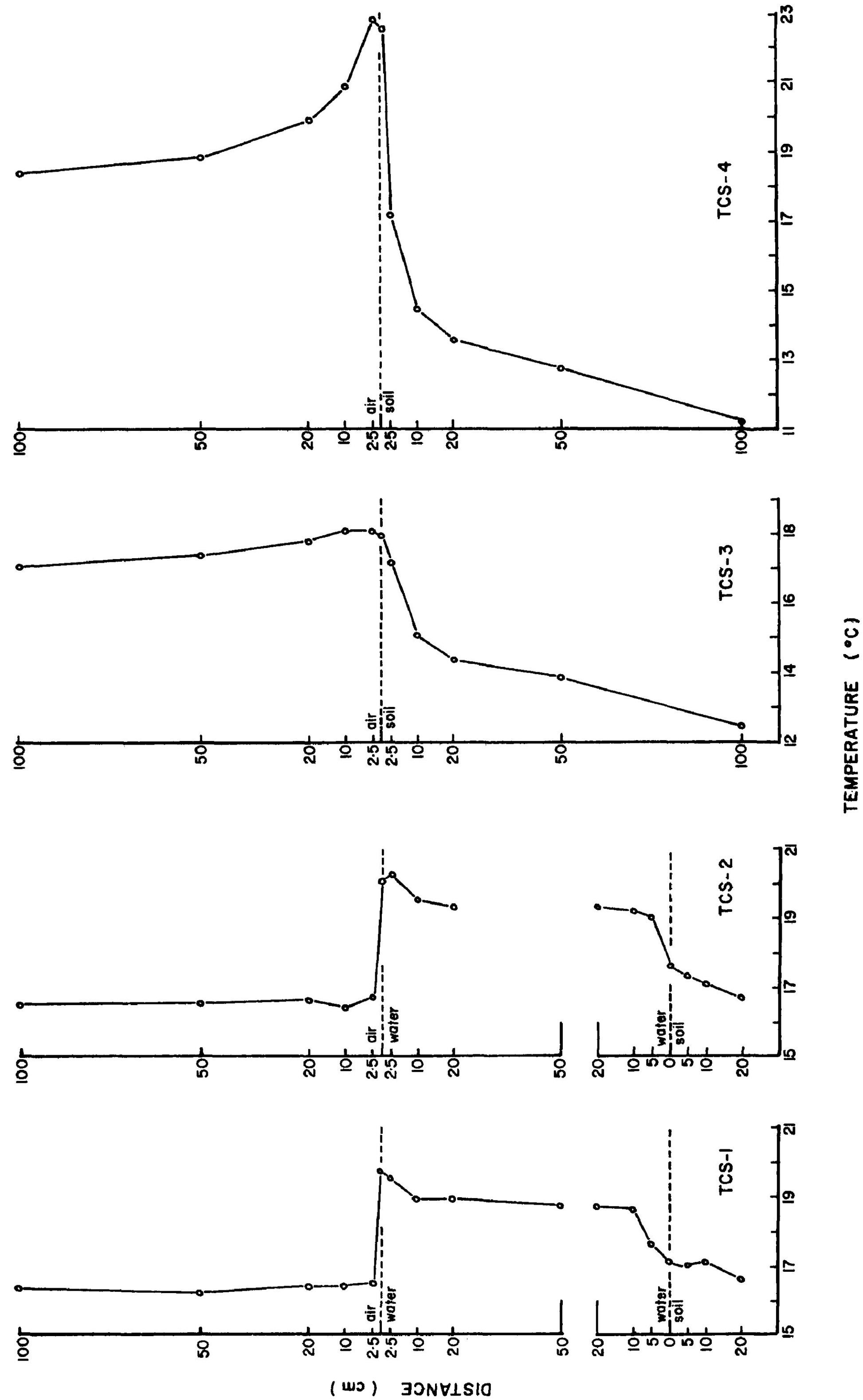

TCS-1
TCS-2
TCS-3
TCS-4
air
water
soil
TEMPERATURE (°C)
DISTANCE (cm)

Figure No. 12

A summary of the data presented in Figure No. 12 can be found in Appendix E.

Figure No. 13 and No. 14 summarize the temperature conditions in the air, water, and soil, at the individual thermocouple sites, for the date of highest and lowest air temperature recorded during the period of study, and the point (inversion) where the general trend of temperature decline was reversed temporarily.

The highest mean air temperatures were recorded on July 13th, the lowest on October 12th, and the inversion on October 5th. On this latter date, the air temperature rose an average of 4.2C^{o} over that of the previous week.

At the two water sites, TCS-1 and TCS-2, the temperatures of the air and the water, on a given date, show relatively little spread, a matter of 4C^{o} at the most. The temperature throughout the body of the water appears fairly uniform on the day recorded, the majority of the stratification being in evidence in the top and bottom 10 centimetre layers.

The pattern of temperature distribution in the air and in the top 10 centimetres of the soil at TCS-3, with the possible exception of the 10 centimetre soil reading on July 13th (high), closely resembles that of the aquatic environment at TCS-1 and TCS-2. Below the 10 centimetre soil reading, the pattern at TCS-3 is quite similar to that at TCS-4. Soil temperatures at the 100 centimetre mark at the shoreline site TCS-3 are slightly higher than those for the same depth at TCS-4.

An increase in temperature at the air-soil interface is quite apparent at TCS-4, while being considerably reduced in amplitude at TCS-3.

Figure No. 13

VERTICAL PROFILE - HIGH and LOW DAY RECORDED, and INVERSION

HIGH	July 13
INVERSION	October 5
LOW	October 12

Recorded at individual thermocouple standards, TCS-1 and TCS-2.

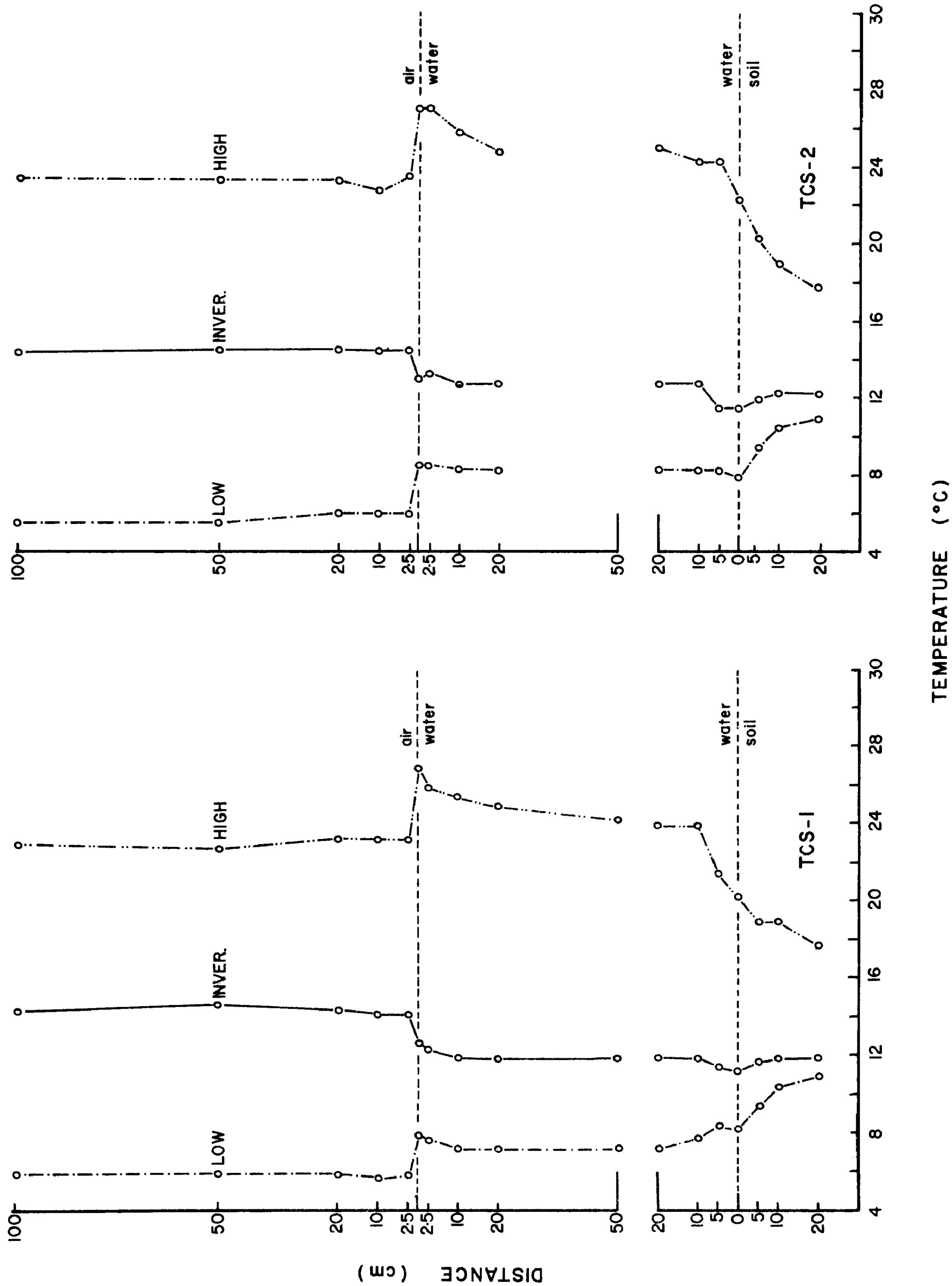

TCS-1
TCS-2
LOW
INVER.
HIGH
air
water
water
soil
TEMPERATURE (°C)
DISTANCE (cm)

Figure No. 13

Figure No. 14

VERTICAL PROFILE - HIGH and LOW DAY RECORDED, and INVERSION

HIGH	July 13
INVERSION	October 5
LOW	October 12

Recorded at individual thermocouple standards, TCS-3 and TCS-4.

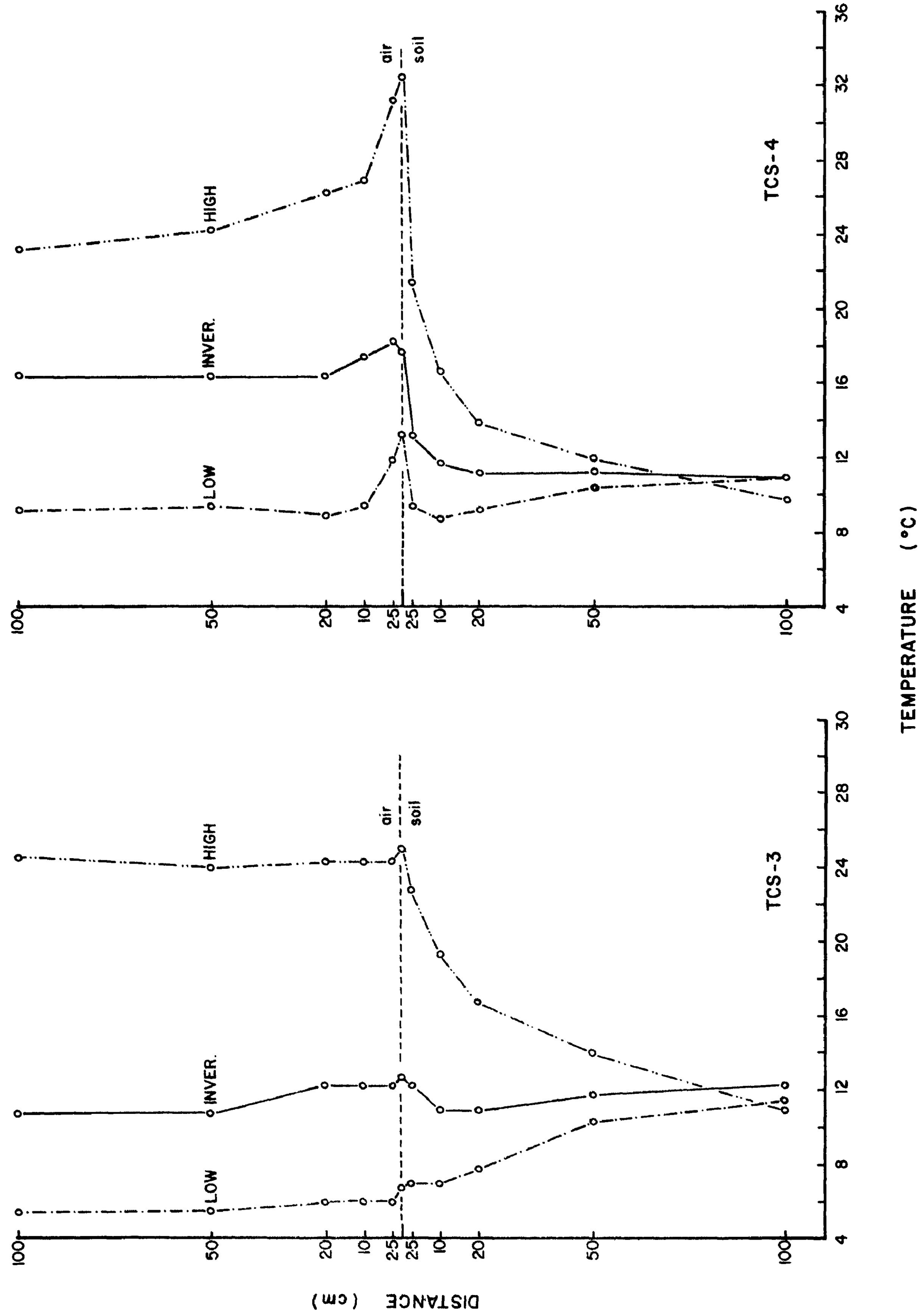


Figure No. 14

A summary of the data illustrated in Figure 13 and 14 will be found in Appendix D.

Figures No. 15 , 16, and 17 summarize the air-water and air-soil temperatures, recorded weekly, at the 2.5 centimetre level above and below the interface, for TCS-1, TCS-3, and TCS-4.

The temperature of the water at TCS-1 remains considerably warmer than the air above it until September 14th, when they are both the same. After this point, they closely parallel each other. Variations in the temperature of the air at TCS-1, as is the case at TCS-3 and TCS-4, display a greater range than the water or soil adjacent to them.

The distribution of temperatures of soil and air at TCS-3 is intermediate between the aquatic (TCS-1) and the terrestrial (TCS-4) habitats. Here the temperatures of soil and air are quite similar, with a maximum differential of about 3C^{o} only.

By comparison, Figure No. 17 illustrates greater extremes of temperature fluctuation, both above and below the air-soil interface. The variation in soil temperatures is more pronounced at TCS-4, and the fluctuation in air temperatures reach their maximum at this site.

A summary of the data for the above figures will be found in Appendix D.

Figure No. 18 is a comparison of mean temperatures for air, water, and soil, over the period of study from June 30th to October 12th, by individual thermocouple standards.

The mean air temperature over the land at TCS-4 is 2.9C^{o} higher than that at TCS-3, and 4.1C^{o} higher than TCS-1 and TCS-2. The differential between the latter two being 0.1C^o.

The mean water temperature at TCS-2 is 0.7C^o higher than that at TCS-1, and both are higher, by 2.4C^o and 3.0C^o, than the mean air temperatures at TCS-1 and TCS-2 respectively.

Mean soil temperatures for the top 20 centimetres of the soil were compared, as this distance was common to all four sites. The mean temperature of the 20 centimetre layer of soil at TCS-2 is 0.2C^o higher than that at TCS-1, 1.4C^o higher than that at TCS-3, and 2.1C^o higher than the mean soil temperature at TCS-4.

Mean soil temperatures for 1 metre in depth, are compared for TCS-3 and TCS-4. The mean temperature at TCS-3 is 1.1C^o higher than that at TCS-4.

A summary of the data for Figure No. 18 will be found in Appendix F.

Figure No. 15

WEEKLY TEMPERATURE - TCS-1

2.5 centimetres above surface of water.

2.5 centimetres below surface of water.

Figure No. 16

WEEKLY TEMPERATURE - TCS-3

2.5 centimetres above surface of soil

2.5 centimetres below surface of soil

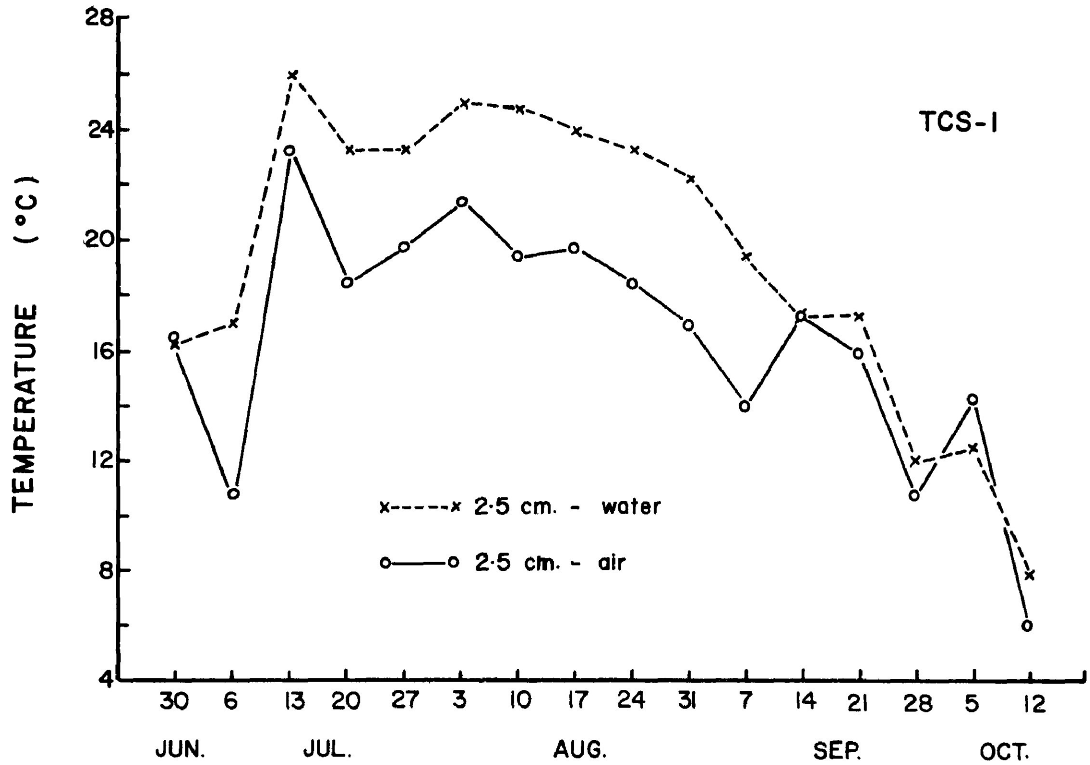


Figure No. 15

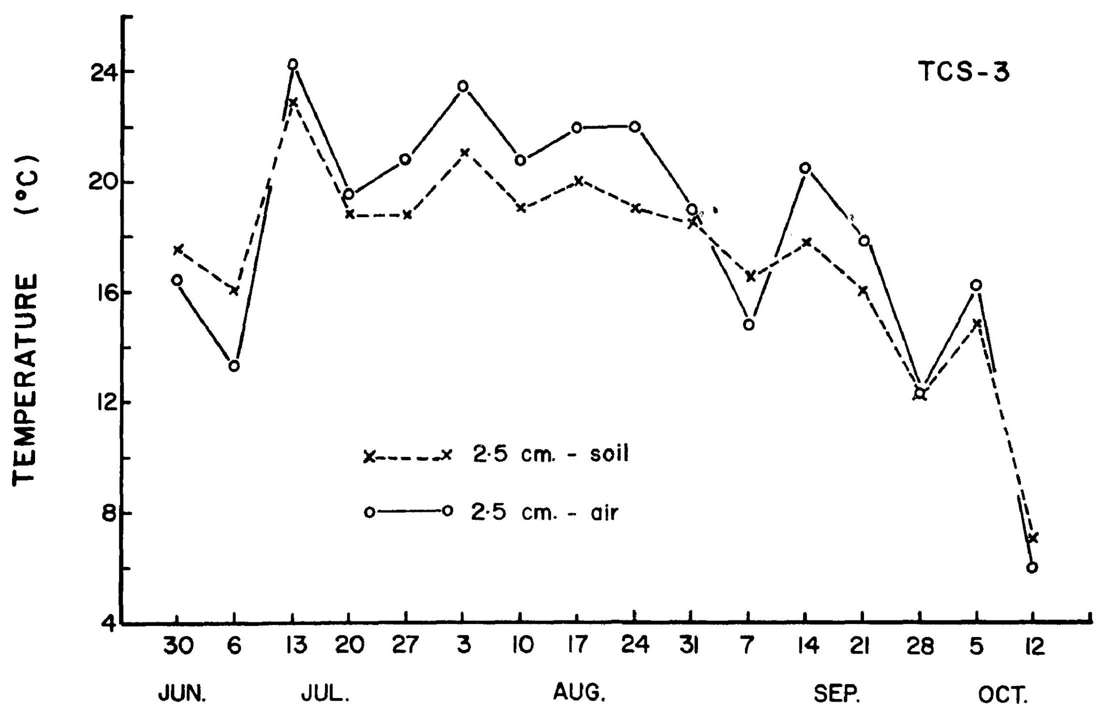


Figure No. 16

Figure No. 17

WEEKLY TEMPERATURE - TCS-4

2.5 centimetres above surface of soil.

2.5 centimetres below surface of soil.

Figure No. 18

COMPARISON OF MEAN AIR- WATER - SOIL TEMPERATURES

At individual thermocouple standards

TCS-1, TCS-2. TCS-3, TCS-4.

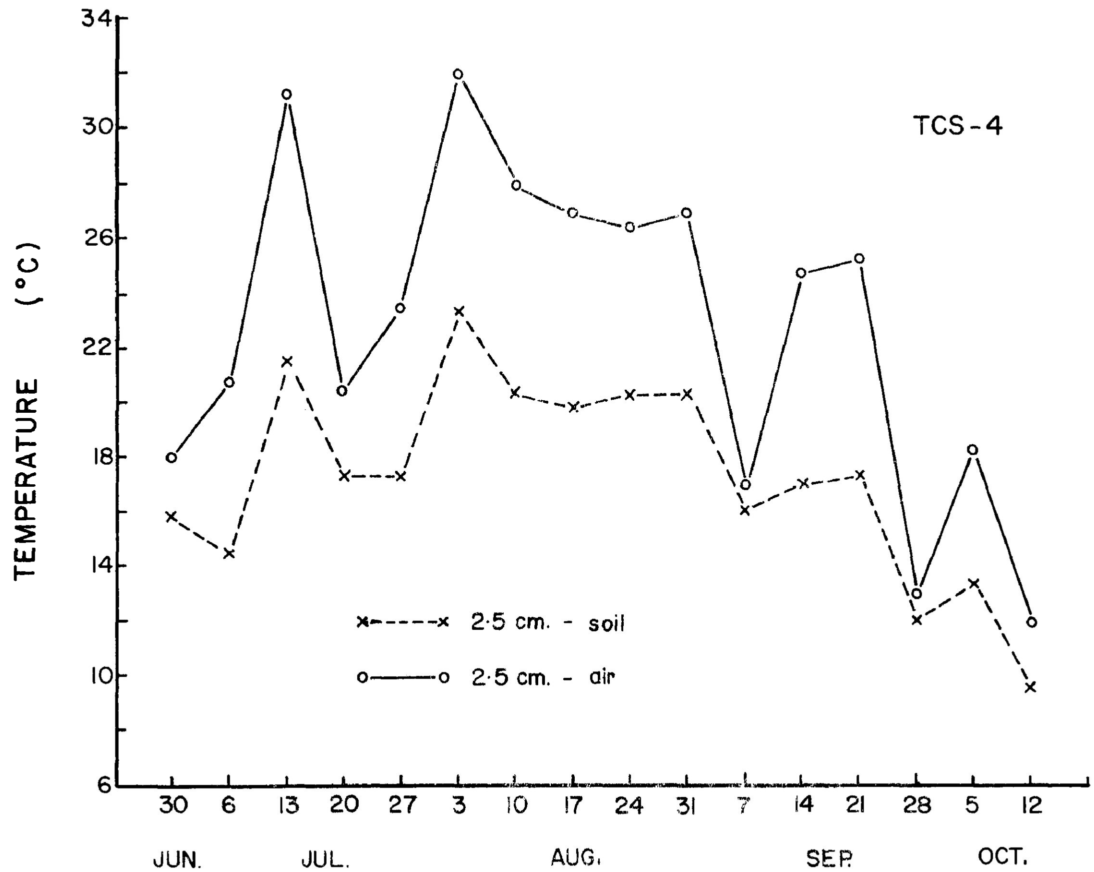


Figure No. 17

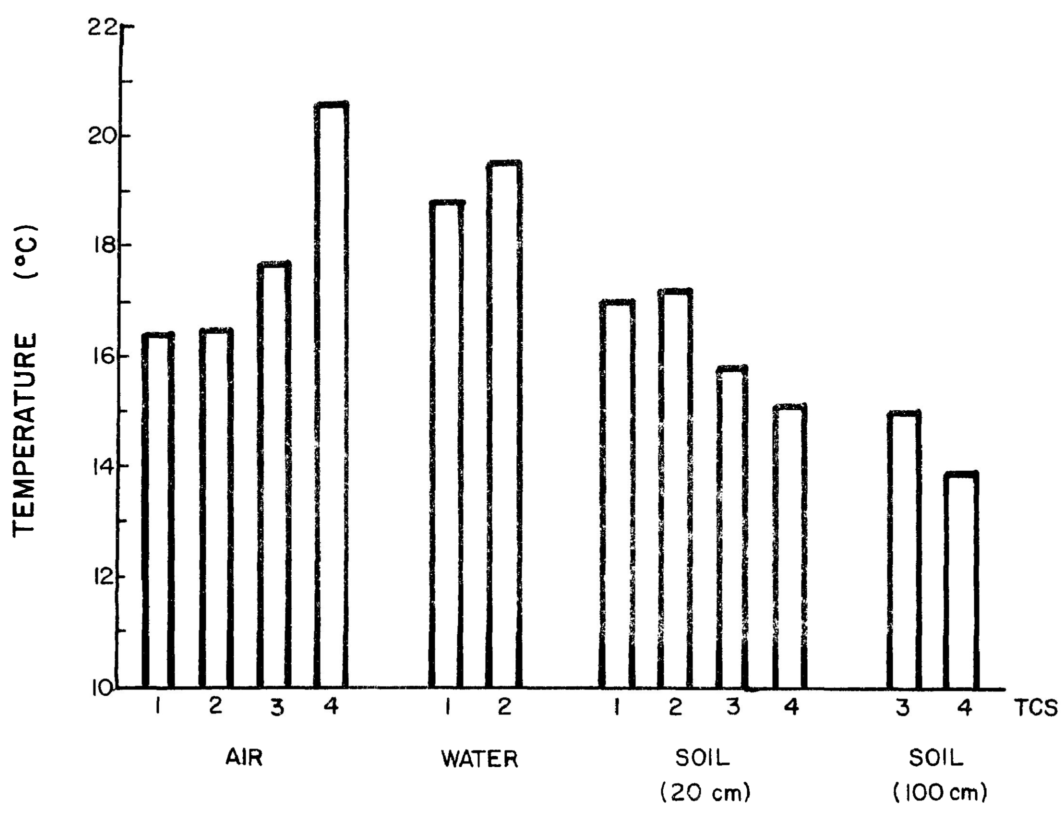


Figure No. 18

Figure No. 19 summarizes the mean air, water, and soil temperatures for the first (0900 hours - August 11th to 0600 hours - August 12th) 24 hour period, and the second (0900 hours - August 12th to 0600 hours - August 13th), by individual thermocouple standard.

The readings for period No. 1 were taken under clear skies, and with light winds. Period No. 2 had complete cloud cover, little to no air movement, and intermittent light rainfall.

Temperatures within the main body of water appear uniform, with some stratification evident, to varying degrees, in the top and bottom 10 centimetre layers of the water. A decrease in mean temperature with an increase in depth, is apparent at both TCS-1 and TCS-2, in both water and substrate, in the vicinity of the water-soil interface.

Mean air temperatures at all four sites were higher for the second 24 hour period, but the mean water temperatures at TCS-1 and TCS-2 displayed the reverse trend, those of the first 24 hour period being the higher.

Although there is some difference in the mean air temperatures at TCS-3 and TCS-4, a matter of 2C^{o} maximum, very little variation appears in the mean temperatures of the soil at these two sites.

The data upon which Figure No. 19 is based, will be found in Appendix H.

Figure No. 19

VERTICAL PROFILE - MEAN PERIOD TEMPERATURE

First and Second 24 Hour Periods.

Recorded at individual thermocouple standards, TCS-1, TCS-2, TCS-3, and TCS-4.

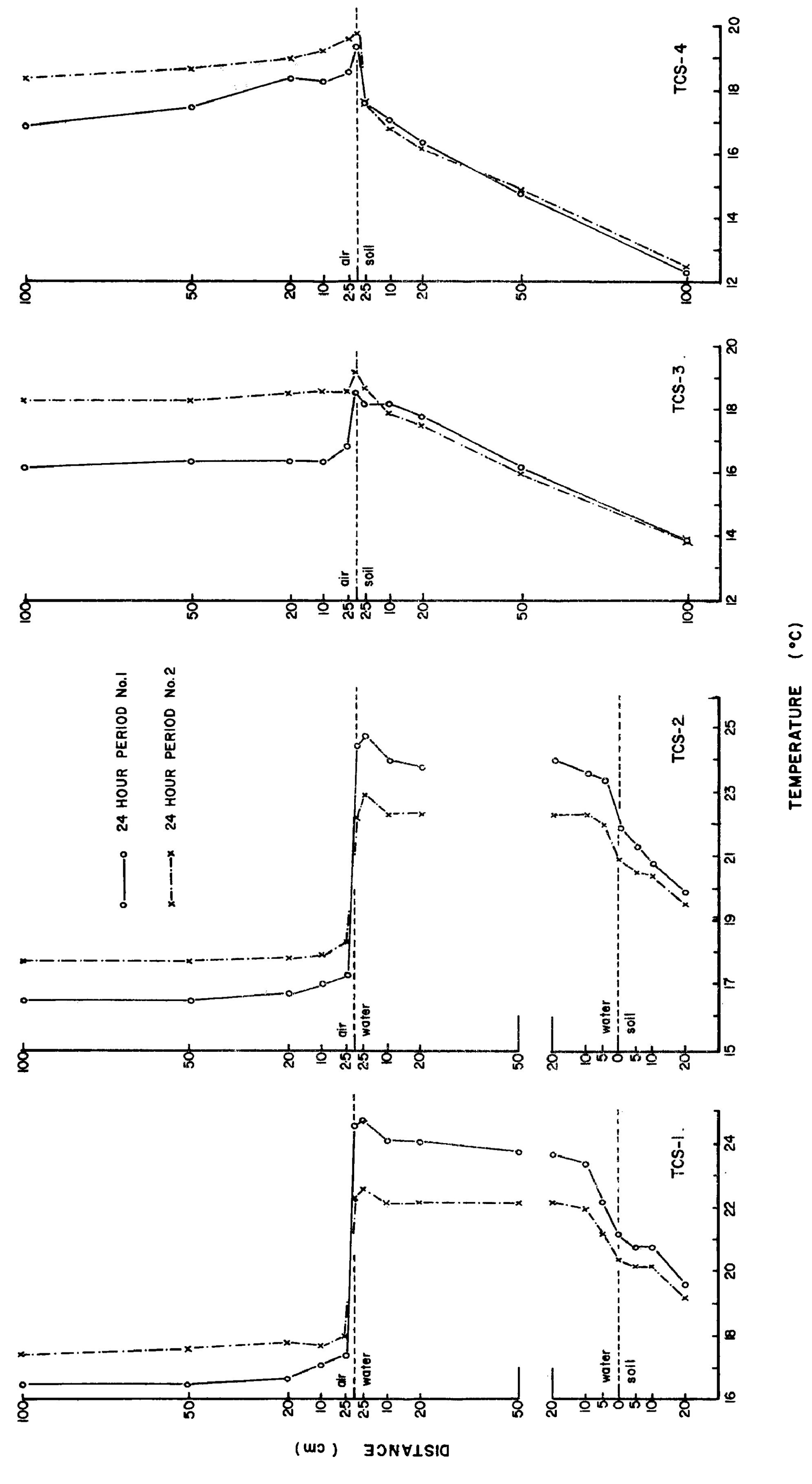

TCS-1
TCS-2
TCS-3
TCS-4
24 HOUR PERIOD No.1
24 HOUR PERIOD No.2
air
water
soil
DISTANCE (cm)
TEMPERATURE (°C)

Figure No. 19

Figure No. 20 illustrates the vertical temperature profiles based upon the high and low individual readings obtained during the 48 hour period. The high reading was obtained at 1500 hours on August 11th, while the low reading was obtained at 0600 hours on August 12th.

The temperature of the water at TCS-1, for both the high and low readings, remains higher than that in the air. Temperature distribution throughout the central portion of the water body remains uniform, with the majority of the stratification restricted to the upper and lower 10 centimetre layers. The temperature of the water decreases as it approaches the substrate, in the 10 centimetre layer above the soil, and continues to decrease with an increase in depth in the substrate.

Temperature distributions at TCS-3 and TCS-4 are quite similar in the soil, in the air, and at the interface. A slight increase in the surface temperature at the air-soil interface, for the "low" period at TCS-3, is missing at TCS-4.

While the temperature of the water has dropped between the 0900 and 0600 hour readings, by a maximum of $2.6C^{o}$, the temperatures recorded for the substrate at TCS-1, and those for the soil at TCS-3, and TCS-4 show little variation below the 20 centimetre mark.

The general slope of the temperature gradients in the soils has been from upper right to lower left.

The data used in the preparation of Figure No. 20 will be found in Appendix G.

Figure No. 20

VERTICAL PROFILE - HIGH and LOW TEMPERATURE - 48 HOUR PERIOD

HIGH	1500 hours	August 11th.
LOW	0600 hours	August 12th.

Recorded at individual thermocouple standards, TCS-1, TCS-3, and TCS-4.

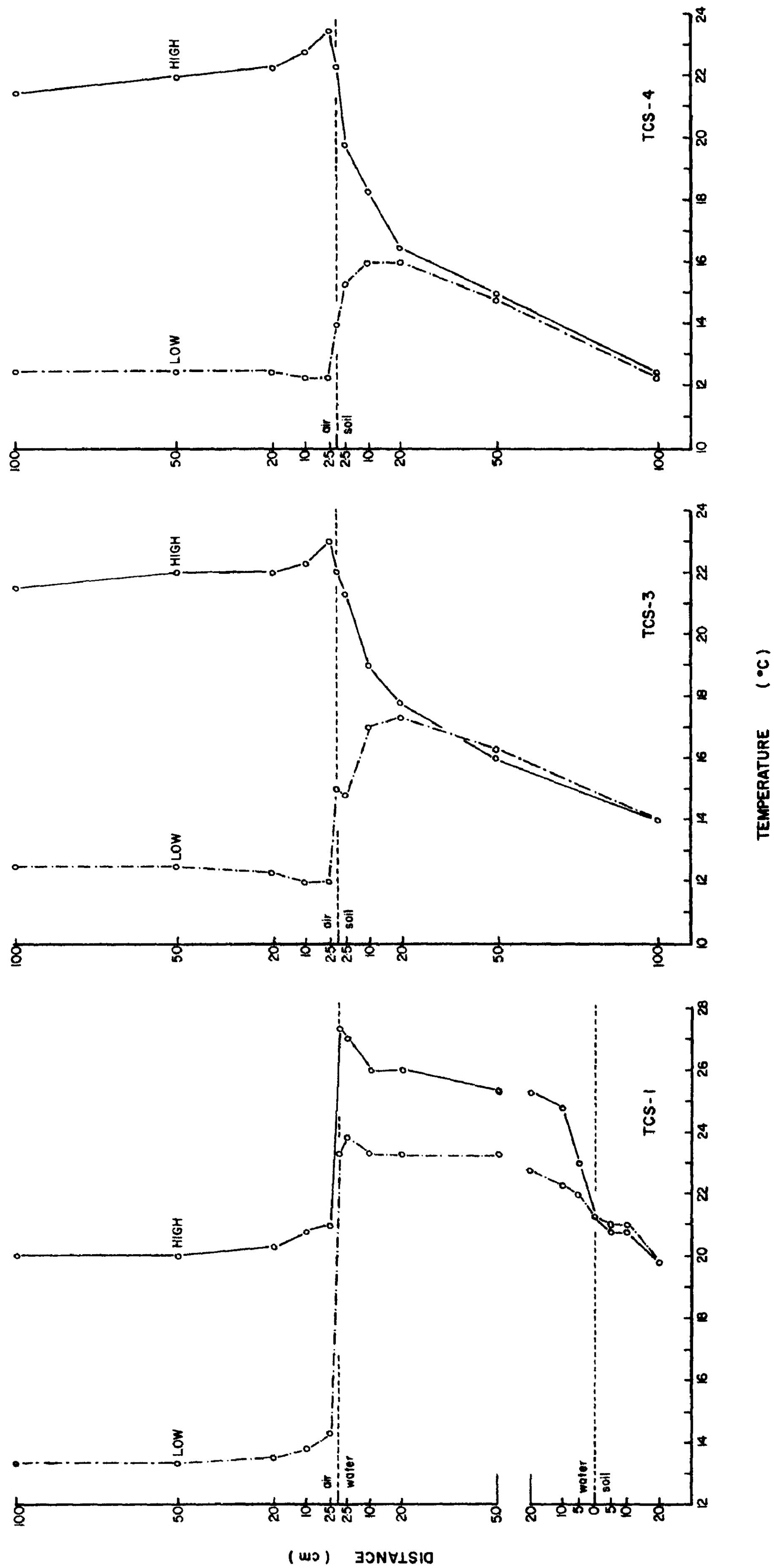

HIGH
LOW
air
soil
water
TCS-4
TCS-3
TCS-1
TEMPERATURE (°C)
DISTANCE (cm)

Figure No. 20

The data summarized in Figure No. 21 illustrates the distribution of temperatures at the 2.5 centimetre level above and below the air-water interface at TCS-1, and the same distance above and below the air-soil interface at TCS-3 and TCS-4. The period covered was from 0900 hours on August 11th, to 0600 hours on August 13th.

The fine broken lines on either side of the 2100 hour readings for August 11th, at TCS-1, result from an error in the potentiometer readings. The readings at 2100 hours, therefore, are estimates only, based upon the normal performance of the thermocouple elements at TCS-3 for the same period, and in no way is it suggested that these temperatures were existent at these points at this time.

The data upon which these figures are based may be found in Appendix G, the interpolated figures for TCS-1 and TCS-2 have been placed in parenthesis.

At TCS-1, the water temperature for the entire period of readings remains at least 4C^{o} above that of the corresponding air temperature, with a fluctuation of 10^{o}C at 2400 hours on August 11th.

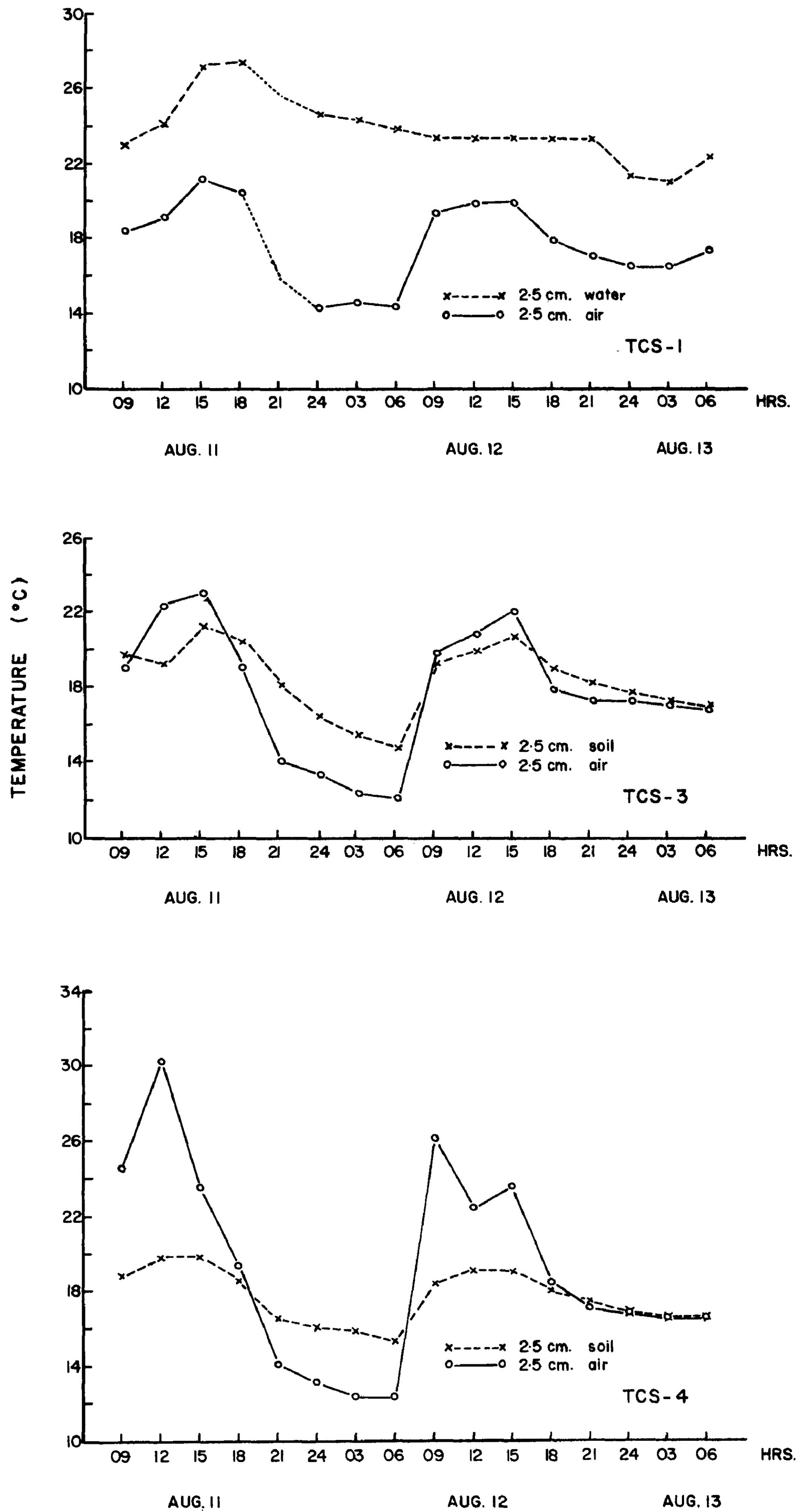
Variation in the air temperature at TCS-1, although modified when compared to that at TCS-3 and TCS-4, is greater than that found at the 2.5 centimetre mark in the water. While the air temperature over the three sites ranges from 30.6^{o}C at 1200 hours on August 11th at TCS-3, to 12.0^{o}C at 0600 hours on August 12th at TCS-4, the range for the water went from a high of 27.3^{o}C at 1800 hours on August 11th, to a low of 21.0^{o}C at 0300 hours on August 13th. Soil temperatures displayed a range from 14.8^{o}C at 0600 hours on August 12th at TCS-3, to 21.3^{o}C at 1500 hours on August 11th.

Figure No. 21

WEEKLY TEMPERATURE

2.5 centimetres above and below the interface.

Recorded at individual thermocouple standards, TCS-1, TCS-3, and TCS-4.



<u>Figure No. 21</u>

TEMPERATURE FACTOR

II - FLOATING MAXIMUM-MINIMUM RECORDING THERMOMETERS:

Methods:

The shifting of surface waters over the length and breadth of the lake by the action of the wind, is of major interest in connection with the distribution of heat within the lake waters. As a result of a certain degree of turbidity and of the presence of dissolved organic and inorganic substances in the water, much of the incoming solar radiation is trapped in the upper layers of the water mass. As some portions of the lakeshore waters receive considerable shading during the day, (eg: the east corner and the southeast shore), it is of importance to know if a differential exists in the distribution of heat energy, and if this is in any way involved, either directly or indirectly, with the distribution of aquatic macrophytes.

In order to obtain the weekly variation in surface temperature, the weekly maximum and minimum temperatures, and the distribution of heat over the surface of Grassy Lake, four floating maximum-minimum recording, mercury-in-glass thermometers were used. These were distributed over the area of the lake, one each at the mid-point of the northeast (No. 1), southeast (No. 2), southwest (No. 3), and northwest (No. 4) shoreline.

The Taylor No. 5459 Maximum and Minimum Registering Thermometers were secured diagonally, by means of Acco fasteners, to one surface of a 12" X 12" X 2" block of styrofoam insulation. The opposite side of the block, as well as the edges, were covered by a double layer of dark green plastic sheeting for purposes of camouflage. (Photograph No. 9).

The units were then floated in water of a minumum depth of 30 centimetres, and so located that they were free to move about in the wind, or up and down with the variation in lake water level, without striking the shore or other fixed objects. In all cases they were within 5 metres of the shore.

The position of the submerged thermometer would make it possible to record the temperature of the top 2.5 centimetres of the water (Platt and Griffiths 1964). Readings were recorded once a week, at about 1100 hours on Sunday. The indices were then reset for the following week.

Photograph No. 9

Plastic covered square of styrofoam insulating material, cont-taining on the underside, the maximum-minimum recording thermometer. The Unit is moored to the aerial extension of the deadfall, by a length of flexible copper wire, permitting considerable freedom of movement. The slide-fastener portion of the Acco Fasteners used to secure the recording unit to the block, are just visible through the plastic covering on top of the float.

All thermometers were calibrated, and the scales adjusted, at the commencement of the project. No further calibration checks were made during the research period. At the conclusion of the work, another calibration check was made, and all four units were found to be registering within 1 F°.

One additional unit was installed, with the hygrothermograph, in the Fraser "birdhouse". This served mainly as a check for the other instrument, but the readings for this unit are included with those for the floating thermometers, in Appendix I.

Results:

The weekly maximum and minimum readings for the surface temperature from the four floating units will be found in Appendix I. The weekly mean maximum, mean, and mean minimum temperatures, for the floating units only, are tabulated in Appendix J.

The following table lists the mean minimum and maximum temperatures, for the period of study, by stations. Temperature - °C.

STATION	No.1	No.2	No.3	No.4	MEAN
Mean Minimum Temperature	14.8	15.0	14.8	15.3	15.0
Mean Maximum Temperature	22.2	21.2	23.1	22.8	22.3

On one occasion the float was found to have broken loose from the mooring, and on another the maximum index was found to have become lodged in the expansion chamber. As a consequence, three readings have been discarded, and of the total of 142 readings, only 139 can be considered valid.

Although there exists some variation in the maximum and minimum temperature readings from station to station for a given week, the differences are not extreme. There remains the possibility that the indices could have been shifted in the capillary tubes by the action of the waves, although it was not possible to obtain any idea of the extent of such a shift, if indeed one did exist.

The mean maximum and minimum temperatures, as outlined in the above table, serve to illustrate the even distribution of heat over the surface layer of the lake.

THE TEMPERATURE FACTOR

III - TEMPERATURE PROBE

Methods:

The horizontal distribution of heat energy over the surface is intimately involved with the vertical movement within the mass of the body of water. The wind will move the surface waters, with their increased heat content in the spring and summer months, piling them up against the downwind shores. Here the influences of shoreline environment are added, and the waters are forced below the surface to return upwind as internal currents in the epilimnion, or in the case of Grassy Lake, the entire water mass.

To ascertain the effectiveness of this wind-dominated internal system of heat distribution, a thermistor probe was employed to obtain readings throughout the depth of water, in all portions of the lake.

When combined with data obtained from the thermocouple and surface recording units, a three dimensional picture of overall uniformity of temperature emerges for Grassy Lake.

A TP-01, No. 209 thermistor temperature probe was mounted at the tip of a 6 foot hollow aluminium rod, calibrated in centimetres, which in turn was connected to a Model 401 temperature readout module (Oceanographic Engineering Corporation, La Jolla, California).

By means of this apparatus, 51 temperature readings were obtained. Of these, 43 readings were taken in water of various depths in the vicinity of the shoreline, and 8 readings were equally spaced on a line running the length of the central portion of the lake.

Readings were taken on August 24th, 1969, between 1200 and 1400 hours. The air temperature dropped from 21.6 ^{o}C at the beginning of the reading period, to 20.8 ^{o}C at 1400 hours. The day was clear and warm, with a moderate wind blowing from the south-southwest.

Temperature checks were taken at all sites planted in wild rice, and at those sites that would tend to illustrate variation in water temperatures due to depth or degree of protection from the effects of the wind.

Results:

The temperature of the surface waters at all 8 stations located in the central portion of the lake remained constant at 23.0 ^{o}C. Readings taken immediately above the substrate, at depths of between 100 and 120 centimetres, varied between 22.0 ^{o}C and 22.8 ^{o}C, with a mean of 22.4 ^{o}C.

The surface temperature in front of the mat along the northeast end, and those along the southeast shore, remain consistent with those found in the centre of the lake. The single exception in this area was noted at the wild rice planting site No. 2, in the east corner, where the average depth of water was 30 centimetres, somewhat sheltered from the wind, and where both surface and bottom temperatures were 1C^{o} above those recorded at the other sites.

The southwest shore of the lake is protected from the effects of the south-southwest winds. Those readings taken in the relatively deep water, 50 to 120 centimetres, remained similar to those obtained in the main body of the lake. Readings taken in the shelter of the shoreline vegetation, in the shallow water, and over the exposed rock shelf, ran as high as 26.8°C.

Surface and bottom temperatures in the deeper water along the northwest shore remained in the vicinity of 23.0°C and 22.0°C respectively. The inshore readings, however, especially those obtained in water between 5 and 25 centimetres in depth, were appreciably higher. These reached 26.5°C over the sand substrate, in 5 centimetres of water, at wild rice site No.9 (WNW corner), and 27.0°C over the sand at wild rice site No. 11 (NNW shoreline), at a depth of 3 centimetres.

TEMPERATURE FACTOR

Discussion:

Daubenmire (1959) urges caution with regard to the use of the mean value in the presentation of data. While useful in summarizing data and outlining an overall trend, the mean tends to hide the extreme value, and to ignore certain aspects such as the length of the day. Thus while means are used throughout this report, the values for the extremes are included where possible.

The data obtained from the thermocouples, with the exception of the 2100 hour readings for TCS-1 and TCS-2 on August 11th, may be considered accurate within $\pm 0.5^{o}C$. These data should be considered as relative, for the purposes of comparison, and not as absolute values.

Extreme wave action was not a problem throughout most of the research period. The effects were felt, however, upon two occasions when the water drenched the 2.5 centimetre element in the air. This occured at TCS-1, on August 24th and September 14th, at element No. 5.

Precipitation during the period of readings was rare, only presenting a problem during the second of the two 24 hour periods, on August 12th and 13th. On two occasions drops of rain hit the sensing elements, with instantaneous reaction of the needle of the potentiometer, and readings were retaken where possible.

It is believed that sufficient shading was provided for all elements, both extended and secured close to the tubing. Every effort was made to assure that there was as little interference with the movement of air as possible.

Data obtained from the floating maximum-minimum recording thermometers was believed sufficiently uniform, on a week to week basis, to suggest that the readings could be employed in the preparation of a general picture of the distribution of heat over the surface layers of the lake. As noted in the section on the methods employed, the action of waves and the use of the floats by birds may have disturbed the indices, and therefore a certain degree of caution is recommended.

While only a single series of readings was attempted with the thermistor probe, it is believed that the picture of heat distribution thus obtained is reasonably representative of the general situation prevalent under similar conditions of incoming radiation, air movement, and air temperature. The pattern suggested by the temperature probe is confirmed by data at the thermocouple standards.

Mean air, water, and soil temperatures for the period of research, displayed in Figure No. 12, demonstrate the ability of this body of water to act in the capacity of a heat reservoir, the decreasing ability of the soils to conduct heat with a decrease in moisture content, the uniformity and lack of stratification existent in the central portion of the vertical water column, the positive net balance of heat during the summer months, the dampening effect of increased soil moisture on the fluctuation in surface temperature, and the possible role played by the wind in the distribution of heat energy throughout the water mass.

Geiger (1961) states that shallow lakes and ponds do not have sufficient mass of water to act as efficiently as larger bodies of water in the capacity of heat reservoirs. The presence of wind over the surface of these smaller units, serves to thoroughly mix the water, thus facilitating the loss or gain of heat energy.

The slope of the temperature gradient for all soils during the period, shows a positive heat balance, and increased conductivity with increased moisture content (Geiger 1961).

Uniformity of temperature in the vertical column of the water decreases as the shoreline is approached. The majority of the temperature variation appears in the top and bottom 10 centimetre layer of the water. Fluctuation in the upper layer may be due to heat exchange with the air mass, increased heat adsorption influenced by turbidity, friction between air and water masses, evaporation, and possible condensation. Influences on the bottom layer may include such factors as increased adsorption of incoming radiation by the bottom sediments and reradiation of the heat to the water mass, and activities of microorganisms and rooted macrophytes, with resultant exchange of heat at the water-substrate interface (Geiger 1961, Ruttner 1963, Moss 1969). The lack of stratification agrees with the findings of Geiger (1961), Eriksen (1966), Miller & Rabe (1969), and Moss (1969).

The dampening effect of the saturated soil at TCS-3 can be clearly seen in Figure No. 12. The mean surface temperature at this site is lower than the surface temperatures of the water at TCS-1 and TCS-2. The surface at TCS-3 is saturated black organic muck, approximately three centimetres in thickness, and is exposed to both wind and incoming solar radiation. It is suspected that although considerable heat would be absorbed at the roughened and black surface of the muck, heat loss due to evaporation to the air and conduction to the soil would modify any extremes at this point.

The role of the wind in mixing the waters of a body of water is referred to in most texts and papers dealing with heat in water, but the main references used were Hutchinson (1957), Geiger (1961), and Ruttner (1963).

No evidence was found to support the existence of a metalimnion or thermocline, and the water of Grassy Lake may be looked upon as being entirely within the bounds of the epilimnion. Figure No. 13 illustrates the fact that mixing throughout the entire depth of the lake is indeed a fact. The high and low daily extremes of air temperature are shown in vertical profile, with accompanying water temperature gradients. The water at TCS-1 and TCS-2 is seen to be within 2 to 3C^{o} of the temperature of the air.

On October 5th, air temperature increased after a steady decline over the several previous weeks, and even though the readings were taken under cloudy conditions, with warm air, fog, and light wind, the water temperature remains close to that of the air, and uniform throughout the depth of the water.

The transfer from the positive to the negative heat balance took place in the vicinity of September 28th. (See Appendix D). The reversal in the slope of the temperature gradient in Figures 13 and 14, can be clearly seen to be underway on October 5th, and well established by October 12th, in the soils at all four sites.

The higher moisture content of the soil at TCS-3, compared with that of TCS-4, gives the profiles of the former the appearance of being intermediate between the aquatic and terrestrial sites. Temperature fluctuations at the surface are dampened, and closely resemble those in the 100 centimetre vertical air column above them.

Maximum surface temperatures are reached at the terrestrial site, and the importance of tolerance to extremes of temperature, both in time and space, by plants and animals, is demonstrated here.

Changes, therefore, in the temperature of the air, appear to be quickly followed by changes in the same direction in the water. Response to change in temperature of the adjacent media is slower in the soils, but the effect is felt to a greater depth, with reduction in time lag, as the degree of saturation of the soil increases, within limits (Geiger 1961).

A comparison of temperatures of air, water and soil in the layer 2.5 centimetres on either side of the interface, not only provides an opportunity to test the correlation with regard to heat exchange, but points out the nature of the temperature regime so vital to many plants and animals living wholly or partially within this layer.

Figure No. 15 confirms the fact that the water in the late spring and summer months is able to store heat to a certain extent. The balance remains positive until late summer, when shorter day-length, reduced angle of incidence and increased reflection of incoming solar radiation, cooler air temperatures with increased wind and precipitation, all serve to reduce the heat content of the water mass to the point where, (after September 14, Figure No. 15) the two are kept almost in balance, dependent upon day by day climatic conditions.

The temperatures at the air-soil interface at TCS-3 (Figure No. 16), remain relatively parallel throughout the season, with the temperature of the air generally a little higher than that of the soil. This suggests the influence of the terrestrial environment, where air temperatures reach their maximum (Figure No. 17). The exceptions to the rule appear on September 7th and October 12th. Readings on both of these days followed periods of cloudy skies and moderate to strong north-northeast winds. Although the heat balance at the interface on these dates is negative, the fluctuation of temperature in the soil is considerably less extreme than in the air.

The situation at TCS-4 (Figure No. 17), is the reverse of that found at TCS-1. Here the variation in the temperature of the air reaches a maximum, and fluctuation in soil temperatures is greater than that at TCS-3, or the water at TCS-1. Air temperatures at the terrestrial site always exceed those of the soil, and at no time did the soil appear able to store sufficient heat to offset variation in air temperature.

A summary of mean air, water, and soil temperatures, for the entire study period, is presented in Figure No. 18.

Mean air temperatures over the water are considerably lower than those over the land, due in part to loss of heat to the evaporative process, and the fact that solar radiation falling on the surface of the water is almost completely utilized (Geiger 1961).

Mean water temperatures, higher than all but terrestrial air temperature, reflect the high rate of radiation absorbtion by the water, and the resultant increase in heat due to adsorption in the water by dissolved and suspended materials. The mean water temperature at TCS-2 is slightly higher (0.7C^{o}) than at TCS-1, and this is probably due to an increase in amount of incoming solar radiation reaching the bottom sediments, where the resultant build-up of heat would be transferred, in part at least, to the water above the interface. Also of significance is the increased reflection of light from the bottom, and the build-up of warmer surface waters moved by the wind to the vicinity of the shallow shoreline.

Mean soil temperatures in the top 20 centimetre layer at all four sites, are highest in the bottom sediments at TCS-2, and lowest at the terrestrial site, TCS-4. This reflects the influence of the positive heat balance with the water at TCS-1 and TCS-2, and the poor conductivity of the drier sandy soils at TCS-4 (Geiger 1961). The increase in conductivity with increased moisture content is illustrated by the higher mean temperature at 100 centimetres, in the soil, at TCS-3.

Correlation coefficients were calculated from data contained in Appendix F, and the results are summarized in the table below:

NO.	VARIABLES	CORRELATION COEFFICIENT	
		TCS-1	TCS-2
1.	Weekly Mean Air Temperature Weekly Mean Soil Temperature	+0.810	+0.814
2.	Weekly Mean Air Temperature Weekly Mean Water Temperature	+0.862	+0.854
3.	Weekly Mean Water Temperature Weekly Mean Soil Temperature	+0.965	+0.969
4.	Weekly Mean Air Temperature Weekly Mean Water Surface Temperature	+0.954	

No. 1 to 3 above were based on data obtained from the thermocouples. No. 4 correlates the weekly mean air temperature obtained from the hygrothermograph unit, with weekly mean water surface temperatures recorded by the floating maximum-minimum thermometers. All coefficients were positive, and all displayed a high degree of correlation between the factors.

The higher coefficient for No. 4, when compared with No. 2, is due to the fact that only the surface layer next to the air mass was measured in the former case, while the mean temperature for the entire water mass was used in the latter. Also, No. 4 included means recorded over the period of the entire week, while No. 2 included data recorded on one set day of the week only.

These strongly positive correlations point to the uniformity of the temperature regime within the water mass of Grassy Lake. Heat is obviously transferred with relative ease from air to soil through the water, and from water to soil and water to air in the case of the higher water temperatures. On the basis of these figures alone, there does not appear to be any barrier to the transfer of heat energy, and it is therefore unlikely that any permanent stratification will be found to exist.

Data on the diurnal fluctuation of temperature was obtained over a 48 hour period, with readings taken at 3 hour intervals. The first 24 hour period was clear and warm, the second cloudy with light, intermittent rain. Please refer to Figure No. 19.

Mean air temperatures for the second period were slightly higher than those for the first, reflecting the influence of the period of bright sunshine between 0600 and 0900 hours on August 12th, when the cloud cover appeared. (See also Figure No. 21). While air temperatures dropped slighty with the advent of the cloud layer, they did not reach the low of the previous night, and along with the temperatures of the soil at TCS-3 and TCS-4, levelled off in the vicinity of 17^{o}C. Only the water remained high, in the area of 22^{o}C.

The loss of heat from the ecosystem during the night of August 11th and the early morning of August 12th, was being replaced rapidly when the source was hidden by cloud about 0915 hours. While some loss was apparent after this point, it was considerably reduced, and the mean air temperature of the second 24 hour period remained higher than that of the first.

Mean water temperatures reflect the positive radiation energy balance during the clear weather of the first 24 hour period, the losses to the heat sink of the clear night skies through reradiation of heat energy, and the lack of incoming solar radiation during the second 24 hour period. Loss of heat to the air from the upper 2.5 centimetre layer of the water is evidenced at both TCS-1 and TCS-2, (Figure No. 19), for both 24 hour periods, and shows a slight increase during the second period.

Mean air temperatures over the land vary slightly more than those over the water, at TCS-3 only. Mean soil temperatures show little fluctuation, even in the vicinity of the interface.

High and low extremes during the 48 hour period illustrate the capacity of the water to retain a certain amount of heat. For both high and low reading periods at TCS-1, (Figure No. 20), heat is being conducted to the air from the water, and heat is still being added to the substrate.

The loss of heat from the surface layers of the soil, espe-ially at TCS-3 where evaporation has a very strong influence, is obvious at the time of the low readings. The higher reading at the 50 centimetre ground element at TCS-3 for the low series of readings, illustrates not only the increased ability of the wetter soils to conduct heat, but also the tendency to retain some of the heat through the high heat capacity of water. The drier soils at TCS-4 are cooler below the 20 centimetre soil element, than those at TCS-3.

A comparison of the temperature regimes in the 2.5 centimetre layer surrounding the interface at TCS-1, TCS-3, and TCS-4, for the 48 hour period (Figure No. 21), shows a considerable degree of similarity with those for the overall period (Figures No. 15, 16, & 17).

The overall pattern within the main body of water, as far as the distribution of heat energy is concerned, is one of uniformity.

Permanent or seasonal stratification, with respect to the establishment of an epilimnion, thermocline, and hypolimnion, was not found within the lake. Normal stratification in the upper and lower layers ($\pm$ 10 centimetres), was present as a result of the exchange of energy at the interface.

The processes at work in Grassy Lake are active throughout the entire body of water, a situation often confined to the epilimnion of larger, seasonally stratified lakes.

It would appear that the wind is the main contributor to the mixing process, and on the basis of observations made during the late spring, summer, and early fall of 1969, the absence of wind from the surface of Grassy Lake is common only during the night hours. As a result, the distribution of gases, heat energy, nutrients, as well as phytoplankton and zooplankton, takes place throughout the entire body of the lake.

CHAPTER IV

WILD RICE

(*Zizania aquatica* L.)

WILD RICE

Introduction:

Evidence of the presence of wild rice, *Zizania aquatica* L., at the Mitchel Dam archaeological site in Minnesota, would indicate the importance of this grain to the native peoples of the area as long ago as 1000 years (McAndrews 1969). The value of wild rice as a staple in the diet of the Indian peoples has been noted in the reports of the early explorers of North America (Jenness 1963). Although no longer a necessary part of the food supply of the natives to-day, wild rice has become of proven economic value as a gourmet speciality.

Deep concern has been expressed with regard to the welfare of the Indian peoples. The introduction and establishment of further rice fields, the more efficient use of the present crops, the possible controlled cultivation of the grain, and improved marketing techniques, may offer a partial solution to the problem. Consideration should also be given to the value of wild rice in the more efficient use of available lands, as an agricultural crop, in the field of wild life management, and in areas of recreation. To assure the most effective use of the plant, however, considerable research remains to be done.

Rogosin's "An Ecological History of Wild Rice" (1951), serves as an excellent review of work done with *Zizania aquatica* to that date. An extensive bibliography is included.

Considerable research has been done since the time of Rogosin's report. Moyle (undated) "Wild Rice - Minnesota's Native Grain", Moyle and Kruger (1964), and Moyle (1967) cover many of the historic, economic and ecological aspects of the grain. Stoddard (1957) in a progress report, describes the methods and results of the introduction of wild rice to a prepared and artificially flooded area, with a view to the possible cultivation of the crop on hitherto unproductive (with respect to commercial crops), land.

Neilson (1964), and in personal communication with the author, has summarized the work carried out by the Department of Agriculture in the Province of Saskatchewan, and added a report on the work undertaken by Vicario and Halstead (1967, unpublished) in connection with the problems of overcoming dormancy in wild rice seed, as well as those involved in attempts to establish the grain outside the limits of the Canadian Shield. It was felt at the time of this report, that competition was among the most important of the limiting factors.

The question of seed dormancy has been studied by Simpson (1966), and Halstead & Vicario (1969). The methods of afterripening used by Simpson were applied by Thomas & Stewart (1969) in preparation for growth chamber studies in connection with research into the effects of different water depths on the growth of wild rice. The influence of water on rice grown in prairie soils was reported by Weber & Simpson (1967). Steeves (1952) also covers this aspect.

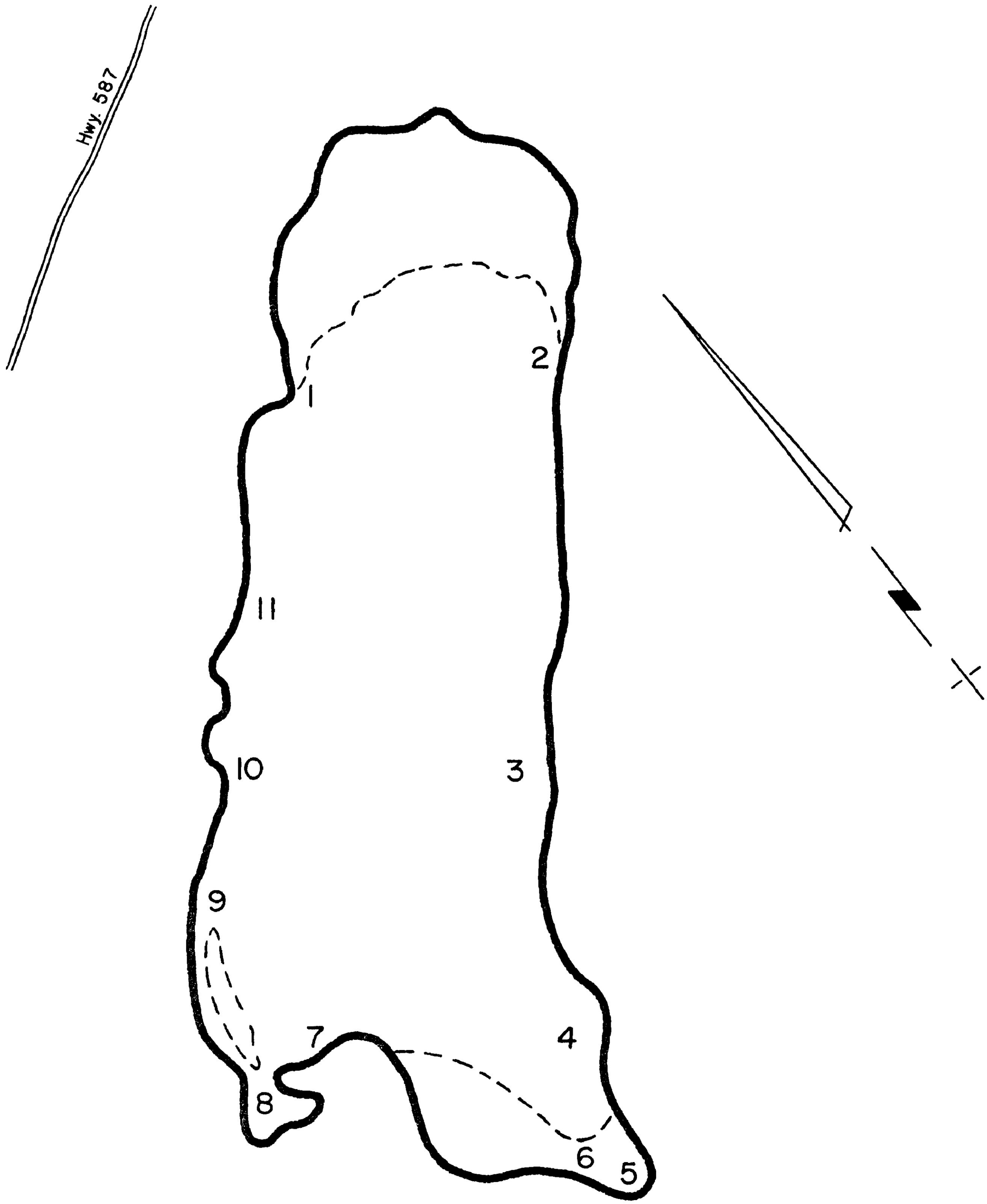
As a preliminary step in what is hoped will develop into an extended programme of research, a small quantity of wild rice seed was introduced into Grassy Lake in the fall of 1968, in an attempt to ascertain if such a crop would become established under the existing conditions. Every effort was made to place the seed in a variety of sites.

Grassy Lake was chosen as the site for future experimental work for a number of reasons. It is a small, shallow lake, accessible by road, though little used by the permanent and transient populations of the area and by reason of the fact that it is situated within the boundaries of Sibley Provincial Park. The nature of the shoreline is varied, offering several different types of growth sites, and some protection from the wind. The water is slightly alkaline (pH 7.8). Vegetative communities are numerous, and include both hardwood and softwood tree species, an open grass-sedge community, floating and semi-floating bog communities, and emergent, floating-leaved, and submerged aquatic species. The substrates are varied, and include dark brown and black muck, clay-silt, rock shelf, sand, and broken rock or gravel. Figure No. 22 identifies the planting sites, hereinafter referred to by number.

Due to the time limits imposed by the nature of this study, it was decided that research be carried out initially in connection with the air, water and substrate temperatures in that portion of the littoral shelf where the majority of the wild rice became established.

History:

No records are available to indicate the fact that *Zizania aquatica* has ever been native to this lake. Attempts were made to introduce the species in the 1930's, and these proved quite successful on a temporary basis. Although the crop was able to re-establish itself in a minor way, it failed to become a permanent part of the lake vegetation.



GRASSY LAKE

PLANTING SITES — WILD RICE

SCALE : I Centimetre = 25 Metres

Successful crops were harvested by members of the Cross family, and it may well be that insufficient seed remained after harvesting to insure a crop of required density to enable it to survive the following season (J. D. Cross, Mrs. S. Halter, personal communication).

Methods:

In the fall of 1968, approximately 7.5 Kg. of wild rice seed became available from the area of Whitefish Lake, Ontario. This was a poor production year, and the existing crop was heavily infested by fungi and insect larvae.

The seed was harvested during the second week in September, and returned to Lakehead University, where it was stored in water, in a controlled climate chamber, at approximately 10°C.

On October 14, 1968, about 5 Kg. of the seed were removed from the chamber, and broadcast by hand in eleven selected sites around the perimeter of Grassy Lake. The majority of the plantings took the form of a strip about one metre in width, at right angles to the shoreline, and which extended from a water depth of 5 centimetres near the shore, to a depth of approximately 100 centimetres. The exceptions to the strip planting method were sites 1, 5, and 8, where the seed was broadcast over the limited area available.

The remainder of the seed, about 2.5 Kg., was retained in the climate chamber, where the temperature was dropped over a period of 10 days, to the vicinity of 3°C. The temperature was maintained at this level until the spring of 1969. The water was changed every 48 hours from stock previously located in the chamber.

Eleven Kilograms of seed were obtained from the Whitefish Lake area, in the fall of 1969. This was planted in Grassy Lake, on September 14th., of the same year. An area of 60 metres by 70 metres was planted next to the shore, between sites 3 and 4. About 0.5 Kg. of the seed was planted in each of two additional sites, at the original site No. 1, and in a small bay between sites 7 and 8. Every effort was made to confine the more recent plantings to areas not previously sewn with seed, so that any successful attempt to re-establish the crop by shattering of seed from the 1968 plantings would be immediately obvious to the observer, in the spring of 1970.

Results:

(a) Germination of seed stored in the controlled climate chamber was noticed around the end of the first week in May, 1969. Four random samples were removed from the chamber and analysed for percentage germination.

The following table summarizes the results of the germination check.

SAMPLE:	No.1	No.2	No.3	No.4
Weight - grams:	30	27	24	27
Total number of seeds:	524	426	419	421
Total seeds germinating:	184	184	165	183
Total Seeds not germinating:	33	26	32	41
Total damaged seeds:	307	216	222	197
% germination, undamaged seeds:	84.8	87.7	83.8	81.8
% germination, all seeds:	34.8	43.2	39.4	43.5

Average germination, undamaged seeds: 85.3%

Average germination, all seeds: 40.3%

(b) Germination became apparent at Grassy Lake on May 19th, 1969, when the initial leaves of the plants, between 1 and 2 inches in length, were observed at three sites along the northwest shore. Germination and initial shoot growth were confirmed at all sites by May 24th.

By June 7th, the floating leaf stage was in evidence, at least to some extent, at all sites.

Varying degrees of thinning was observed in the exposed stands, No. 1, 9, 10, and 11, on June 15th. The surface of the lake had been subjected to strong south and southwest winds during the previous week, with subsequent uprooting and removal of plants then at the floating leaf stage of development. Later observation would seem to confirm this assumption, as plants were found to have established themselves in the shelter of the shoreline debris to the north and northeast of the original planting sites.

At this stage, some slight damage to submerged and floating leaves was observed, due possibly to aquatic organisms.

Some plants had emerged above the surface of the water by July 6th. On August 9th the first flower heads appeared, and by August 24th the seed heads were rapidly filling out. At this time, some seed could be removed by gentle pressure from the fingers, but no natural shattering was observed.

The shattering of the seed commenced about September 3rd or 4th, and continued until September 14th. As a result of heavy damage

Photograph No. 10

Zizania aquatica L., planting site No. 3, at the mid-point of the southeast shore of Grassy Lake, about the end of the third week in August, 1969. The yellow-brown colour of the water, and the turbidity is well illustrated in this photograph. The small boulder or broken rock nature of the shoreline is visible in the background.

Photograph No. 11

A single plant of *Zizania aquatica*, at planting site No. 9 on the northwest shore of Grassy Lake, about the end of the third week in August, 1969. Originally in about 50 to 60 centimetres of water, it now stands in 30 centimetres. A count of 27 stems, in varying stages of development, was made at the time this photograph was taken.

sustained by the crop through the action of ducks and geese, and to a somewhat lesser extent by moose, the exact limits of the period of shattering were difficult to ascertain. All sites had been devastated, and further seed crop eliminated, by the end of the second week in September.

When the frequency of damage to the crop increased with the influx of migratory birds, every effort was made to see that as much ripe seed as possible reached the bottom of the lake. The traditional Indian method of inducing shattering by means of tapping the heads gently with a short stick, in this case a canoe paddle, was employed. It is hoped, therefore, that sufficient seed has become lodged in the substrate to demonstrate viability in the spring of 1970, and thus indicate that further study of environmental conditions in relation to the introduction and establishment of wild rice will be both feasible and desireable.

Discussion:

The successful introduction and establishment of wild rice, to slightly varying degrees, was obtained at all sites. In the shallow areas, 30 centimetres and under, heavy tillering (stooling) was observed. This also became apparent at the deeper plantings as the water level dropped during the late spring and summer.

The plants showed good growth form, with heights above the water of between 100 and 120 centimetres. The heads were full for the most part, and showed no sign of fungal or insect damage. Root systems were well developed, especially those in the shallower water, where tillering was evident.

As a result of the extensive drop in the level of the lake, 27 centimetres by the week of September 14th, plants originally established in the shallow water near the shore were found growing above the level of the water, in the muck, sand, and broken rock or gravel areas. These plants displayed fairly good development through to the fruiting stage, and in some cases showed heavy tillering.

During the floating leaf stage, uprooting and dispersal of plants as a result of the action of wind and wave was evident. Those plants uprooted from the original sites developed well after they had become re-established in the protection of the windfall and vegetation along the shore of the lake.

On the basis of the above information, it is felt therefore, that care should be exercised in the choice of sites for planting, in order to see that as much protection as possible is provided against the adverse effects of wind and wave action. Lakes whose levels are maintained by such artificial means as the control dam, should be suspect from the point of view that rising water levels during the floating leaf stage of development could prove detrimental, or possible disastrous to the crop. Previous records of annual variation in lake level, where available, should be examined, and planting sites chosen that would insure that portions of the crop would not be found "high and dry", so to speak, at a critical point in their development.

Plants in the Grassy Lake area appear to have successfully established themselves on a variety of substrate types. It is not possible at this early stage, without further detailed study, to comment with any degree of confidence upon the relative suitability of the various soils.

Further research into the chemical nature of the water and soil, the availability of nutrients, competition within the plant and animal communities, and the physiology of the plant itself, is required before an accurate assessment of the habitat is possible. However, in the light of the initial observations only, it would appear that varying water level, and the movement of air with the resulting wave action, may be considered among the more important of the limiting factors in the annual re-establishment of the wild rice crop.

Many questions, a few of which are included below, remain to be answered.

(a) Is Grassy Lake capable of producing a crop of viable seed, which in turn will establish a crop of wild rice on a perpetual basis?

(b) How typical are the conditions in this lake, of other small and medium sized lakes in the area, and how similar are these conditions to those in presently established stands of rice?

(c) What area or density of crop will have to be established in order to overcome natural predation, and the effects of such environmental factors as wind and wave action, in order to provide sufficient seed for the perpetual re-establishment of the crop?

(d) What effect will the successful introduction of wild rice have on the present enviroment of the lake, and what are, or could become, the limiting factors in this situation?

CHAPTER V

GENERAL DISCUSSION

and

CONCLUSIONS

GENERAL DISCUSSION

Grassy Lake is a relatively small body of water, with the characteristics of both a pond and a lake (Hutchinson 1957, Geiger 1961). Located as it is near the tip of the Sibley Peninsula, the lake is exposed to the force of winds moving over the surface of Lake Superior, which surrounds the narrow peninsula ($\pm$ 11 Kilometres) on the east, south, and west.

While Thunder Bay to the west is only 25 Kilometres in width, Black Bay runs well inland down the east side of the peninsula, for a distance of 65 Kilometres north-northeast of Grassy Lake. As a result, the velocity, temperature, and moisture content of the air moving across the face of Grassy Lake will be considerably influenced by the nature of the medium over which it has passed. The natural trough in which the Lake is situated provides a channel for winds from the northeast and from the south and southwest.

Although the shores are wooded, the area of the lake is sufficiently great so as to reduce seriously the protective effect of the trees, in all but the south corner, and along the southeast shore.

The temperature of the air mass over Lake Superior when compared with that over the land, will be lowest during the spring and summer months. Winds from the east, south and west will have passed over this body of water before reaching Grassy Lake. Only winds from the north will have passed over land for a considerable distance. With the exception of the "Sleeping Giant" (the southwestern tip of the peninsula, elevation 540 metres, or 1768 feet above mean sea level), there is insufficient land mass in the vicinity of Grassy Lake to greatly influence either the character or the movement of the air from Lake Superior.

It is felt, therefore, that the wind must be considered a major environmental factor in the case of this particular ecosystem,

Perhaps the greatest influence of the wind is in the continual mixing of the water mass of Grassy Lake. In this way, heat accumulating in the surface layers of the water in spring and summer, is not only distributed over the surface but also throughout the depth of the lake, and hence into the bottom sediments. The reverse would be true in the fall of the year, when heat is lost to the atmosphere.

Moss (1969) found evidence of both chemical and thermal stratification that persisted over extended periods of time, and he felt that the absence of wind over the surface of Abbot's Pond was the major contributing factor. Analysis of data obtained from thermocouple and thermistor probe in Grassy Lake, fails to supply evidence to support the presence of any stratification other than that normally found in the top and bottom layers of water, under conditions of a positive or negative radiation balance. Certainly, none of these data indicated the existence of a metalimnion or thermocline.

The fact that thermal, and in all probability chemical, stratification cannot remain in existence for any great length of time, is of primary importance. Dissolved and suspended organic and inorganic materials are moved throughout the body of the lake. Nutrients incoming in ground runoff and precipitation, and those released in the water and at the substrate, are probably quickly distributed.

The distribution of carbon dioxide and oxygen in Grassy Lake is equally important. The free or equilibrium carbon dioxide is essential in the buffering of the water. Based upon such evidence as the predominance of dolomitic limestones in the lake basin area, the presence of Chara sp. in quantity (Spence 1967), the encrustations of calcium carbonate on the submerged leaves of Potamogeton amplifolius, the pH readings taken of crushed samples of the red cemented sandstone of the southwest shore (pH - 8.35), and the slight alkalinity of the lake waters (pH - 7.84), considerable buffering must be present. Free carbon dioxide would appear to be in ample supply throughout the waters of the lake. Further measurements of carbonates, both calcium and magnesium, will be of importance in the understanding of the bicarbonate balance in Grassy Lake.

Moss (1969) found an early morning minumum and a late afternoon maximum in the supply of oxygen in Abbot's Pond. Combined with an extended period of stratification, these extremes in the oxygen content of the water could have quite a serious effect on the distribution of plants and animals.

Due to the shallow nature of Grassy Lake, incoming solar radiation is able to reach all portions of the substrate and the submerged and floating plants within the water. The daily production of oxygen from the dense mat of submerged aquatic vegetation covering the bottom of the lake, should be reasonably high. The supply of oxygen could well be enhanced by the photosynthetic activities of the phytoplankton.

The wind would play an active part in the distribution of this oxygen throughout the water mass.

The solubility of oxygen is temperature dependent, decreasing with increasing temperatures. Uniformly high water temperatures in Grassy Lake during the summer months, would tend to reduce the amount of the gas present in the water. Sculthorpe (1967) states that values of up to 200% saturation have been recorded for water in the vicinity of plants, and that this effect can be brought about in part by a rise in the temperature of the water. If such a situation existed in Grassy Lake, the oxygen would be quickly distributed, and if concentrations were high enough, some quantity would be lost to the atmosphere.

Heavy demands are made upon the available supply of oxygen by aerobic bacteria, algae, larger plants and animals, and chemical oxidation, the latter in the surface layers of the bottom sediments in particular. The importance of the supply at the substrate interface will be discussed below.

The degree of turbidity would also appear to be dependent upon the wind. Periods when direct observation of the bottom plant communities was possible were confined for the most part to the early morning hours, and in the complete absence of any air movement over the face of Grassy Lake. Attempts made during windy periods to relocate communities previouly noted, were almost always unsuccessful due to the amount of suspended materials present in the water, and the resultant diffusion and absorbtion of light. In the deeper portions of the lake, a layer of fine sediment appears to settle over the bottom vegetation, eliminating all contrast of green leaves with the brown-black bottom sediments, and making sighting all but impossible except under the most ideal conditions.

The difference in density of suspended materials can be seen to a certain extent by reference to photographs No. 6 and No. 10. The former picture was taken in the morning, after an overnight period of little to no movement of air and the latter in the late afternoon, after a period of moderate winds. While the water in photograph No. 6 is by no means clear, it will be noted that the turbidity is greatly reduced when compared with the water colour in photograph No. 10. There does not appear to be any serious degree of staining to the water. The colour that is apparent to the eye is believed to be the result of reflection from suspended materials.

While the pH of the water mass remained uniform throughout the body of the lake, in the set of readings taken, other studies indicate that hydrogen ion concentration varies both seasonally and diurnally, and therefore further studies of this factor are indicated.

As noted earlier in the thesis, a coefficient of correlation of +0.83 was calculated for the precipitation - water level relationship. This would seem to point out the dependency of Grassy Lake upon the availability of moisture from snow and rain. The drainage basin of the lake is relatively limited, and although some seepage of ground water is to be noted throughout the summer season, the amount of such seepage is greatly reduced at this time. In the absence of a supply of fresh water from a spring or stream, the role of the ground water and the precipitation in supplying additional nutrients to the ecosystem, assumes greater importance.

The soft brown-black bottom soils of Grassy Lake would appear to offer a satisfactory habitat for the dense mat of submerged and floating-leaved vegetation established in the central portion of the lake. Here the effects of wave action are reduced to the minimum. As the shoreline is approached, however, changes are seen in both the density and type of vegetation. The thick mat of bottom ooze tapers out, and the yellow sands of the sub-soil appear. Here the effects of the action of the wind are clearly apparent.

The effectiveness of wave action in undermining the vegetative mats at the northeast end, and west corner of the lake, have been described in detail in an earlier portion of this thesis. At that time, the complete lack of rooted submerged vegetation below the face of the mats was noted.

The southeast shoreline, although rocky and reasonably steep, is protected from many of the adverse effects of wind and wave, and the stands of wild rice, No. 2, 3, & 4, developed well in 80 to 100 centimetres of water. Sufficient muck has accumulated to support a good stand of rice. Seeds that had failed to sink immediately upon planting in the fall of 1968, and had drifted to the coarse gravels of the shore, germinated and developed into productive plants, despite the somewhat doubtful nature of the footing.

The deep organic muck within the open areas of the reed swamp in the west corner of the lake, supported the finest stand of introduced wild rice. Germination of the seed in this area appeared to be tardy, and was probably due to the fact that the seed had become buried in the extremely soft ooze of the bottom, and the initial shoots had had to work their way to the surface before they could be recognized. Once started, development was rapid, producing the densest stand and tallest plants. Tillering in this situation was the rule rather than the exception.

It is in connection with the northwest shore, which receives the greater amount of incoming solar radiation, and is subject to strong influences of the wind, that a most interesting and informative picture emerges. Here the packed yellow sand of the shore area slopes gently out under the water. The inshore portion of the shelf is almost entirely devoid of the type of sediment characteristic of the deeper portions of the lake. The soil test samples of the bottom sediments collected in December, 1969, show a low proportion of carbon at the 15 metre mark from the shoreline, or 4.75%. This rises to a mean content at the 20 metre mark of 19.50%, and it is here that wave action appears sufficiently reduced to allow deposition of the finer organic materials. The decrease in carbon content of the sediment at the 25 metre sample, 12.07%, may indicate a reduction in water deposited materials, and reflect an increase in decomposition in the relatively undisturbed deeper waters.

Partially decomposed organic materials, transported from the shore area, are trapped in the shallow depressions, and among the stems of the emergent vegetation of the shore zone on the northwest shoreline. Rarely are these deposits thicker than 3 to 5 centimetres.

The effect of wave action can be seen in the development of a littoral shelf along the northwest shore of Grassy Lake. The coarser, exposed sands of the water's edge give way to finer deposits as the depth increases. The inshore edge of the layer of bottom ooze becomes apparent, depending upon the degree of exposure, in water between 40 and 80 centimetres in depth.

A drop in the level of the lake water, such as that experienced during the summer of 1969, (27 centimetres maximum), can shift the effectiveness of wave action to a portion of the littoral shelf not normally exposed to these extremes. This will have a serious effect upon the distribution of bottom materials, as well as the plant and animal inhabitants.

It is reasonable to expect, therefore, that the vegetation established in this area of Grassy Lake, would be such that it could successfully withstand the consequences of large fluctuations in water level.

The impression received when viewing the northwest shoreline of Grassy Lake, (see photographs 1, 2, 7, & 8), is one of grass-like vegetation thinning out in the deeper water from a dense growth on the shore. The species involved are Equisetum fluviatile, Eleocharis palustris, Eleocharis acicularis, and Carex spp. The presence of deeply rooted or rhizomatous species on the exposed portions of the littoral shelf, agrees with the findings of Spence (1967).

The submerged and rooted vegetation does not become abundant until a depth of approximately 80 centimetres of water is reached. Potamogeton gramineus appears on the shallow sandy northern portion of the northwest shore, but only because this particular area is in the form of a shallow bay and receives considerable protection. Sparganium angustifolium, Sparganium chlorocarpum, Sagittaria latifolia, Nymphaea tetragona, Nuphar microphyllum, and scorpidium scorpioides are all found established on the northwest shore, but only under the complete protection of windfall or extensions of the reed swamp.

The wild rice planted in the fall of 1968, showed successful germination at all sites in the spring of 1969, and the plants developed well as they reached the floating leaf stage in June. At this point most of the rice along the northwest shore, at planting sites 1,9,10, and 11, disappeared. These plants were later found to be growing well, and in great profusion, among the tangle of windfall along the same shore, but to the northeast of the original planting sites. Average wind speed recorded at the airport in Port Arthur - Fort William for the months of May and June 1969, were 9.5'/sec. and 7.9'/sec. respectively, in both cases the highest in four years.

This evidence points to the probable uprooting and removal of the weakly rooted wild rice plants, as a result of the action of wind and wave.

The distribution of aquatic macrophytes found along the northwest shore could be the result of a number of factors. These would include the high incidence of solar radiation and the resultant increase in soil, water, and air temperatures, the lack of sufficient oxygen and nutrients in soil and water, and the exposure of the shore to the action of the wind and the resultant elutriation present in the soils of the littoral shelf.

The solar radiation reaches a maximum along this shore, and data obtained from the thermistor probe confirms the high water temperatures present in the shallows. In spite of this, genera such as Sagittaria, Sparganium, Nymphaea, Nuphar, and Scorpidium, found throughout other parts of the lake, are located on this shore as well, and in the sheltered sites where temperatures would be higher than those of the exposed zones. It is doubtful, therefore, that temperature alone is directly responsible for the distribution of hydrophytes.

Temperature, however, is intimately involved in the metabolic processes of the vegetation, and with the supply of nutrients and oxygen.

The diffusion of oxygen into the water is a relatively slow process, and a shortage of the gas might seriously curtail the life cycles of the plants in the area, were it not for the constant agitation of the water surface and increased area for diffusion. The fact that the lake is richly supplied with photosynthetic organisms in the form of rooted submerged and floating leaved macrophytes, and phytoplankton, would mean an ample supply of the gas in the daylight hours at least. With the constant mixing action of the wind, the gas would be distributed to most portions of the lake water, with relative swiftness.

The nutrient supply is closely tied with that of the oxygen. In the presence of ample oxygen, the surface of the substrate becomes oxidized, and the nutrients witheld from distribution and use. Both Sculthorpe (1967) and Spence (1967) agree that in such a situation, the rooted hydrophytes have a distinct advantage over those organisms which must obtain nutrients from the surface of the substrate or from the water. The lack of oxygen below the surface of the substrate will mean reduced conditions in the muds, and the availability of nutrient ions. These can be absorbed by the roots of plants so situated.

During the hours of darkness, the supply of oxygen is used up, the bottom sediments become reduced, and ions are released to the water.

In the case of Grassy Lake, these ions would be quickly circulated.

Grassy Lake is richly endowed with rooted macrophytes, while the free-floating types, with the exception of Utricularia, are uncommon. The rooted submerged and floating-leaf macrophytes are confined, for the most part, to the central portion of the lake. Here a supply of nutrients would always be available, despite the condition of the substrate surface, from the depths of the sediment, and where some absorbtion of nutrient materials could take place through the stems and leaves when the supply in the water reached sufficient concentration.

While the oxygen-nutrient supply may influence the presence of the free-floating species, it cannot entirely explain the absence of a species from one portion of the shoreline area, and the presence of the same species within a matter of a few metres, but in a sheltered location.

It would seem highly probable that the distribution of hydrophytes on the littoral shelf of the northwest shore of Grassy Lake, is largely dependent upon the degree of exposure to the effects of the wind. The lack of accumulated organic materials, the changing water levels, the shifting and sorting of the substrate materials, the exposure to the force of the wind and to the action of the waves, have all but eliminated the delicate or weakly rooted species from the northwest shore. Such species are, however, found to be growing in relative abundance in other parts of the lake, where similar conditions of temperature, oxygen and nutrient supply, and water levels exist, but where shelter is provided against the physical action of wind and water.

CONCLUSIONS

Late spring, summer, and early fall temperatures in Grassy Lake are higher than those of larger, deeper lakes in the temperate regions, but the limited surface area and depth reduce the capacity of this body of water to act as a reservoir for heat energy.

The water temperatures remain close to those of the air, and tend to vary in the same direction. The general increase in water temperature over air temperature during the spring and summer months, is most probably due to adsorption of heat in the upper layers of the water mass by suspended organic and inorganic materials.

The temperature regime of the vertical water column is uniform throughout, and this will lead to a relatively rapid transfer of heat energy in and out of the ecosystem, between the air, water, and the soils.

Temperature fluctuations are least within the substrate, and thus provide the most stable of the environments studied. Variations in water temperatures were only slightly greater than those in the substrate, while those of the air displayed the greatest variation. Air temperatures over the water mass were modified by that medium, but those over the terrestrial habitat are subject to the greatest extremes of fluctuation. The shoreline habitat is intermediate between those of the aquatic and terrestrial sites.

The close proximity of the land mass and the extremes of temperature variation found therein, influence to a certain extent the environment of the littoral shelf and shoreline in general. However, control over this influence is exercised by the presence of considerable air movement, often from the Lake Superior area.

The wind may be considered a major environmental factor in the case of Grassy Lake. It forms a close partnership with temperature in strongly influencing most of the other environmental factors.

By constanly mixing the waters of Grassy Lake, wind is responsible for the uniform distribution of heat energy throughout the waters of the lake, and this is accompanied by the similar distribution of dissolved gases and nutrients, as well as suspended materials. The wind has prevented the establishment of any form of permanent thermal or chemical stratification in the lake.

Resulting in wave action, the wind is instrumental in the shaping of the shoreline, the development of a littoral shelf through the sorting and differential deposition of bottom materials. Along with the physical nature of the soils and the chemical qualities of both soil and water, it is believed to be of importance in the control and distribution of aquatic macrophytes.

In the case of the introduced wild rice, based upon observations made during the 1969 growing season, and in the light of the limited data available at this time, it is to be recommended that considerable care be exercised in the choice of planting sites for the grain. Protection, from the force of the wind and the resultant action of the waves, would appear to be a basic requirement. Widely fluctuating water levels should also be avoided. As the drop in Grassy Lake, though extreme, was in one direction only, this factor did not present a problem.

APPENDIX A

Water Level:

DATE	READING (cm)	CHANGE IN LEVEL (cm)	CUMM. CHANGE (cm)
June 8	44.0		
		-14.0	14.0
15	58.0		
		-1.0	15.0
22	59.0		
		-2.0	17.0
29	61.0		
		-1.0	18.0
July 6	62.0		
		-1.0	19.0
13	63.0		
		-0.5	19.5
20	63.5		
		-1.5	21.0
27	65.0		
		0.0	21.0
Aug. 3	65.0		
		+1.0	20.0
10	64.0		
		-1.5	21.5
17	65.5		
		-2.5	24.0
24	68.0		
		-2.0	26.0
31	70.0		
		+1.0	25.0
Sept. 7	69.0		
		-1.5	26.5
14	70.5		
		-0.5	27.0
21	71.0		
		+1.5	25.5
28	69.5		
		+2.5	23.0
Oct. 5	67.0		
		+1.0	22.0
12	66.0		

APPENDIX B.

Precipitation:

DATE	CORRECTED READING (cm)	CUMM. READING (cm)
June 15	0.5	
22	1.9	2.4
29	0.7	3.1
July 6	0.6	3.7
13	0.4	4.1
20	2.0	6.1
27	0.8	6.9
Aug. 3	3.1	10.0
10	2.3	12.3
17	0.3	12.6
24	0.2	12.8
31	0.3	13.1
Sept. 7	1.7	14.8
14	0.4	15.2
21	0.4	15.6
28	1.9	17.5
Oct. 5	2.0	19.5
12	0.8	20.3

APPENDIX C. - (a)

Air Temperature: (Thermograph) Degrees Centigrade.

WEEK OF	EXTR. HIGH	MEAN HIGH	MEAN	MEAN LOW	EXTR. LOW
June 8	17.0	13.2	8.7	4.1	3.5
15	18.0	14.7	9.6	4.4	2.5
22	19.0	15.1	11.2	7.3	4.0
29	18.0	14.7	10.5	6.3	5.0
July 6	24.0	18.2	13.1	8.0	4.0
13	27.0	22.7	17.2	11.6	11.0
20	21.0	19.7	15.7	11.6	10.0
27	26.5	23.2	18.4	13.5	12.5
Aug. 3	24.5	21.2	17.4	13.6	12.5
10	23.0	20.4	16.5	12.6	10.0
17	24.0	21.2	16.0	10.7	7.5
24	23.5	21.6	17.4	13.2	10.0
31	21.5	19.1	15.2	11.3	8.0
Sept. 7	17.5	15.8	11.0	6.1	3.0
14	20.0	15.6	11.6	7.6	2.0
21	18.5	12.0	9.1	6.1	0.0
28	14.0	11.1	8.3	5.4	3.0
Oct. 5	16.0	10.7	7.5	4.3	2.0

APPENDIX C. - (b)

Moisture Content of Air: (Hygrograph) Relative Humidity - Percent

WEEK OF	MEAN HIGH	MEAN	MEAN LOW
June 8	94	73	53
15	95	72	48
22	94	78	62
29	94	75	56
July 6	93	73	53
13	93	74	55
20	93	76	59
27	93	71	49
Aug. 3	92	76	60
10	92	77	61
17	92	71	49
24	92	75	57
31	92	79	66
Sept. 7	92	73	53
14	93	78	63
21	92	80	68
28	92	79	66
Oct. 5	92	77	63

APPENDIX D — Weekly Temperature Readings (°C) — Thermocouple Standard No. 1

MONTH	June	July				August					September				October	
DATE	30	6	13	20	27	3	10	17	24	31	7	14	21	28	5	12
TC No.																
1	16.8	10.3	23.0	17.8	19.5	21.3	17.3	19.3	19.3	17.0	13.3	18.5	16.0	10.3	14.5	6.0
2	17.0	9.8	22.8	18.0	19.5	21.0	17.3	19.3	19.3	17.3	13.3	18.5	16.0	10.0	14.8	6.0
3	16.3	9.8	23.3	18.5	19.5	21.0	18.0	19.3	19.3	17.3	13.5	19.0	16.0	10.5	14.5	6.0
4	16.3	10.3	23.3	18.3	19.8	21.5	17.3	19.5	19.3	17.3	13.5	18.3	16.0	10.8	14.3	5.8
5	16.5	10.8	23.3	18.5	19.8	21.5	19.5	19.8	18.5	17.0	14.0	17.3	16.0	10.8	14.3	6.0
6	16.5	17.0	27.0	23.5	23.0	25.0	25.3	23.8	23.3	22.3	19.8	17.3	17.8	12.3	12.8	8.0
7	16.3	17.0	26.0	23.3	23.3	25.0	24.8	24.0	23.3	22.3	19.5	17.3	17.3	12.0	12.5	7.8
8	15.8	16.0	25.5	22.3	22.0	24.5	24.0	23.3	22.3	21.8	19.0	17.0	17.0	11.8	12.0	7.3
9	15.0	16.3	25.0	22.8	22.3	24.5	24.3	23.3	22.3	21.8	19.0	17.0	17.0	11.8	12.0	7.3
10	15.3	15.8	24.3	22.5	22.3	24.8	24.0	23.3	22.3	21.8	19.0	16.3	17.0	11.5	12.0	7.3
11	15.3	15.8	24.0	22.5	22.3	24.8	24.0	23.3	22.3	21.8	19.0	16.0	17.0	11.5	12.0	7.3
12	14.8	15.8	24.0	22.3	22.5	24.5	23.3	23.0	22.3	21.5	19.0	16.0	17.0	11.5	12.0	7.8
13	14.8	14.8	21.5	21.5	21.3	22.8	22.0	21.3	20.8	20.3	18.5	15.5	15.8	11.3	11.5	8.5
14	14.8	13.3	20.3	21.0	20.8	22.0	21.0	20.3	20.0	20.0	18.5	15.3	15.5	11.5	11.3	8.3
15	14.0	13.0	19.0	19.8	20.3	21.3	20.5	20.0	19.8	20.0	18.8	15.5	15.8	12.5	11.8	9.5
16	14.0	13.0	19.0	19.8	20.3	21.0	20.8	20.0	19.8	20.0	19.0	15.5	15.8	13.3	12.0	10.5
17	14.0	12.8	17.8	19.0	19.3	19.5	19.5	19.3	19.0	19.5	18.5	15.5	15.3	13.3	12.0	11.0

APPENDIX C — Weekly Temperature Readings (°C) — Thermocouple Standard No.

MONTH	June	July				August					September				October	
DATE	30	6	13	20	27	3	10	17	24	31		14	21	28		12
TC No.																
1	17.0	10.3	23.3	18.3	19.8	20.8	17.8	19.0	20.3	16.8	12.8	19.0	16.3	11.0	14.3	5.5
2	16.5	10.3	23.3	18.3	20.0	21.0	18.0	19.5	20.3	17.0	12.8	19.0	16.3	11.0	14.5	5.5
3	16.5	10.8	23.3	18.5	20.0	22.0	18.3	19.5	20.3	16.8	13.0	19.0	16.3	11.0	14.5	6.0
4	16.0	9.8	22.8	18.5	19.8	20.3	18.3	19.5	20.3	17.3	13.0	19.3	16.0	11.0	14.5	6.0
5	16.8	9.8	23.5	18.3	19.8	21.8	19.5	20.0	20.5	16.5	14.0	19.0	16.3	11.0	14.5	6.0
6	16.8	17.3	27.0	23.3	23.0	25.8	25.3	24.0	24.0	23.0	19.5	18.3	18.0	13.3	13.0	8.5
7	17.0	17.8	27.0	23.3	23.3	25.8	25.3	24.5	24.5	23.3	19.8	18.3	18.3	12.8	13.3	8.5
8	16.0	17.0	25.8	22.8	22.3	25.3	24.8	23.8	23.5	22.8	19.3	17.3	17.8	12.3	12.8	8.3
9	15.8	16.3	24.8	22.8	22.3	25.3	24.0	23.8	23.3	22.8	19.3	17.3	17.5	12.3	12.8	8.3
10	15.5	16.3	25.0	22.3	22.3	25.3	24.5	23.8	23.3	22.8	19.3	17.3	17.8	12.3	12.8	8.3
11	15.5	16.3	24.3	22.3	22.3	25.3	24.0	23.3	23.3	22.8	19.3	17.3	17.8	12.3	12.8	8.3
12	15.5	16.3	24.3	22.3	22.3	25.0	24.0	23.3	22.8	22.3	19.3	17.0	17.0	12.0	11.5	8.3
13	14.8	14.8	22.3	21.0	21.0	22.3	21.8	21.3	20.8	20.3	18.3	16.0	15.8	11.5	11.5	8.0
14	14.3	13.5	20.3	20.8	20.5	21.5	21.0	20.5	20.0	20.0	18.5	16.0	15.8	12.3	12.0	9.5
15	13.8	12.8	19.0	19.8	20.0	21.0	20.5	20.0	20.0	20.0	18.5	16.0	15.8	13.0	12.3	10.5
16	13.8	12.3	17.8	19.0	17.8	20.0	19.8	19.5	19.5	19.8	18.8	16.0	15.8	13.3	12.3	11.0

APPENDIX D   Weekly Temperature Readings (°C)   Thermocouple Standard No. 3

MONTH	June	July				August					September				October	
DATE	30	6	13	20	27	3	10	17	24	31	7	14	21	28	5	12
TC No.																
1	16.0	10.5	24.5	18.5	19.8	22.3	19.0	21.3	20.8	18.3	13.8	20.5	16.8	10.8	15.8	5.5
2	16.5	11.8	24.0	18.3	20.3	22.3	20.3	20.8	20.8	18.5	13.8	20.3	17.3	10.8	16.3	5.5
3	16.5	11.8	24.3	19.5	20.8	22.8	20.5	21.3	21.8	18.5	14.0	21.0	17.8	12.3	16.5	6.0
4	16.8	12.8	24.3	19.5	20.8	23.5	20.5	22.0	22.0	19.0	14.5	21.0	17.8	12.3	16.5	6.0
5	16.5	13.3	24.3	19.5	20.8	23.5	20.8	22.0	22.0	19.0	14.8	20.5	17.8	12.3	16.3	6.0
6	17.5	21.3	25.0	19.8	19.5	21.3	19.5	21.0	19.5	18.5	16.3	18.0	15.8	12.8	15.3	6.8
7	17.5	16.0	22.3	18.8	18.8	21.0	19.0	20.0	19.0	18.5	16.5	17.8	16.0	12.3	14.8	7.0
8	13.8	12.3	19.3	17.8	17.0	18.0	17.8	17.5	17.0	17.5	15.8	13.8	14.0	11.0	11.5	7.0
9	12.3	10.5	16.8	17.0	16.5	17.0	17.0	16.5	16.5	17.0	15.8	13.5	13.5	11.0	11.3	7.3
10	11.3	9.3	14.0	15.3	15.3	16.0	16.5	16.0	15.8	16.3	15.8	13.8	13.3	11.8	11.3	10.3
11	9.5	7.8	11.0	12.3	12.8	13.3	14.0	14.0	14.0	14.5	14.3	13.5	13.0	12.3	11.5	11.5

APPENDIX D   Weekly Temperature Readings (°C)   Thermocouple Standard No. 4

MONTH	June	July				August					September				October	
DATE	30	6	13	20	27	3	10	17	24	31	7	14	21	28	5	12
TC No.																
1	16.8	13.3	23.3	18.3	20.5	24.5	22.0	21.8	21.3	20.3	13.5	22.3	18.8	12.0	16.5	9.3
2	16.0	13.0	24.3	18.3	20.8	26.0	22.0	21.8	22.3	22.3	13.5	22.3	19.8	12.0	16.5	9.5
3	16.3	16.0	26.3	18.5	21.5	29.5	24.0	22.3	23.3	24.8	13.5	23.3	22.0	12.3	16.5	9.0
4	16.8	15.8	27.0	20.0	21.5	31.0	25.3	23.3	24.8	26.0	14.0	23.8	25.0	12.3	17.5	9.5
5	18.0	20.8	31.3	20.5	23.5	32.0	28.0	27.0	26.5	27.0	17.0	24.8	25.3	13.0	18.3	12.0
6	19.0	17.0	32.5	21.3	19.8	28.3	26.0	27.3	27.8	28.5	16.3	25.8	26.0	12.8	17.8	13.3
7	15.8	14.5	21.5	17.3	17.3	23.3	20.3	19.8	20.3	20.3	16.0	17.0	17.3	12.0	13.3	9.5
8	11.3	10.5	16.8	15.5	15.3	18.5	17.3	17.0	17.3	17.3	15.3	14.5	14.5	11.0	11.8	8.8
9	9.8	9.0	14.0	14.5	14.8	16.5	16.0	16.0	16.0	16.3	15.3	13.8	13.8	11.0	11.3	9.3
10	9.3	8.3	12.0	13.0	13.3	14.8	15.0	15.0	14.8	15.3	14.8	13.3	13.0	11.5	11.3	10.5
11	8.0	6.5	9.8	10.5	10.5	12.0	12.5	12.8	12.5	13.0	13.0	12.3	12.0	11.5	11.0	11.0

APPENDIX E

Mean Temperatures: (°C)

THERMOCOUPLE No.	TCS - 1	TCS - 2	TCS - 3	TCS - 4
1	16.3	16.4	17.1	18.4
2	16.2	16.5	17.4	18.8
3	16.4	16.6	17.8	19.9
4	16.4	16.4	18.1	20.9
5	16.5	16.7	18.1	22.8
6	19.7	20.0	18.0	22.5
7	19.5	20.2	17.2	17.2
8	18.9	19.5	15.1	14.5
9	18.9	19.3	14.4	13.6
10	18.7	19.3	13.9	12.8
11	18.7	19.2	12.5	11.2
12	18.6	19.0		
13	17.6	17.6		
14	17.1	17.3		
15	17.0	17.1		
16	17.1	16.7		
17	16.6			

APPENDIX F Weekly Mean Temperatures (°C), Air, Water and Soil. Thermocouple Standards 1, 2, 3, & 4.

MONTH	June	July				August					September				October			
DATE	30	6	13	20	27	3	10	17	24	31	7	14	21	28	-	12		
TCS No. Air																	MEAN	
1	16.6	10.2	23.1	18.2	19.6	21.3	18.0	19.4	19.3	17.2	13.5	18.3	16.0	10.5	14.5	6.0	16.4	
2	16.6	10.2	23.2	18.4	19.9	21.2	18.4	19.5	20.3	16.9	13.1	19.1	16.2	11.0	14.5	5.8	16.5	17.8
3	16.5	12.0	24.3	19.1	20.5	22.9	20.2	21.5	21.5	18.7	14.2	20.7	17.5	11.7	16.3	5.8	17.7	
4	17.2	16.0	27.5	19.5	21.3	28.6	24.6	23.9	24.3	24.8	14.6	23.7	22.8	12.4	17.2	10.4	20.6	
Water																		
1	15.5	16.1	24.7	22.6	22.4	24.5	24.0	23.2	22.4	21.7	19.1	16.6	17.0	11.7	12.1	7.7	18.8	19.2
2	16.0	16.8	25.5	22.7	22.5	25.4	24.6	23.8	23.5	22.8	19.4	17.5	17.7	12.5	12.7	8.4	19.5	
Soil (20 cm.)																		
1	14.2	13.0	19.0	19.9	20.2	21.0	20.5	19.9	19.7	19.9	18.7	15.5	15.6	12.7	11.8	9.8	17.0	
2	14.2	13.4	19.9	20.2	19.9	21.2	20.8	20.3	20.1	20.0	18.5	16.0	15.8	12.5	12.0	9.8	17.2	16.3
3	12.2	12.4	21.0	18.4	18.0	19.3	18.3	18.8	18.0	17.9	16.2	15.8	14.8	11.8	13.2	7.2	15.8	
4	12.3	11.3	17.4	15.8	15.8	19.4	17.9	17.6	17.9	18.0	15.5	15.1	15.2	11.3	12.1	9.2	15.1	
Soil (100 cm.)																		
3	11.6	11.2	13.2	16.9	16.7	17.8	17.3	17.5	17.0	17.1	15.8	15.1	14.3	11.9	12.6	8.4	15.0	14.5
4	10.3	9.3	14.3	14.2	14.2	17.0	16.2	16.1	16.2	16.4	14.9	14.2	14.1	11.4	11.7	9.8	13.9	

APPENDIX G Temperature Readings: (°C) 48 hour period. Thermocouple Standard No. 1

DAY			August 11							August 12					August 13	
TIME	09	12	15	18	21	24	03	06	09	12	15	18	21	24	03	06
TC No.																
1	17.0	17.8	20.0	20.0	(15.3)	14.0	13.5	13.3	19.0	18.8	19.5	16.8	16.5	16.3	15.8	16.8
2	17.0	18.0	20.0	20.0	(15.3)	14.0	13.5	13.3	19.0	19.0	19.5	17.0	16.8	16.3	16.0	16.8
3	17.0	17.8	20.3	20.3	(15.8)	14.5	13.8	13.5	19.0	19.3	19.8	17.5	16.8	16.3	16.0	16.8
4	17.5	18.5	20.8	20.3	(15.8)	14.3	14.3	13.8	19.3	19.3	19.5	17.5	17.0	16.5	16.0	16.8
5	18.3	19.0	21.0	20.3	(15.8)	14.3	14.5	14.3	19.3	19.8	19.8	17.8	17.0	16.5	16.5	17.3
6	23.3	24.0	27.3	26.5	(25.0)	24.3	23.5	23.3	23.8	23.5	23.5	23.8	23.3	21.3	21.3	22.3
7	22.8	24.0	27.0	27.3	(25.5)	24.5	24.3	23.8	23.3	23.3	23.3	23.3	23.3	21.3	21.0	22.3
8	22.0	23.3	26.0	26.5	(24.8)	24.0	23.5	23.3	23.0	22.8	22.8	23.0	22.5	20.8	20.8	21.8
9	22.0	23.3	26.0	26.5	(24.8)	24.0	23.5	23.3	23.0	22.8	22.8	23.0	22.5	20.8	20.8	21.8
10	22.0	23.0	25.3	25.8	(24.3)	23.5	23.5	23.3	23.0	22.8	22.8	23.0	22.5	20.8	20.8	21.8
11	22.0	23.0	25.3	25.5	(24.3)	23.5	23.5	22.8	23.0	23.0	22.8	23.0	22.5	20.8	20.5	21.8
12	22.0	23.0	24.8	24.8	(24.0)	23.3	23.3	22.3	23.0	22.8	22.5	23.0	22.3	20.3	20.3	21.5
13	21.5	21.3	23.0	23.3	(22.8)	22.3	22.3	22.0	21.8	21.8	21.5	22.0	21.8	19.8	19.8	21.0
14	20.8	20.3	21.3	21.8	(21.5)	21.3	21.8	21.3	21.0	20.8	20.8	21.0	21.0	19.3	19.0	20.5
15	20.3	20.0	20.8	21.0	(21.0)	20.8	21.3	21.0	20.8	20.3	20.3	20.8	20.8	19.0	19.0	20.3
16	20.3	20.3	20.3	20.8	(20.8)	20.8	21.0	21.0	20.8	20.3	20.3	20.8	20.8	19.0	19.0	20.3
17	19.5	19.0	19.8	19.8	(19.5)	19.3	19.8	19.8	19.5	19.5	19.0	19.3	19.5	19.0	19.0	19.0

APPENDIX G   Temperature Readings: (°C) 48 hour period. Thermocouple Standard No. 2

DAY			August 11							August 12					August 13	
TIME	09	12	15	18	21	24	03	06	09	12	15	18	21	24	03	06
TC No.																
1	17.0	18.3	20.0	20.3	(15.0)	13.8	13.3	13.3	19.3	19.8	19.8	16.5	16.5	16.8	16.5	16.8
2	17.0	18.3	20.0	20.3	(15.0)	13.8	13.3	13.3	19.3	19.8	19.8	17.0	16.5	16.8	16.5	16.8
3	17.3	18.3	20.5	20.3	(15.3)	14.0	13.3	14.0	19.0	19.8	19.8	17.3	16.8	16.8	16.5	16.8
4	18.0	18.8	20.8	20.3	(15.5)	14.3	13.5	14.0	19.3	19.8	19.8	17.8	17.0	16.8	16.5	16.8
5	18.0	19.0	21.5	21.5	(15.8)	14.3	13.5	14.0	19.8	20.3	20.3	17.5	17.3	17.3	17.0	17.5
6	22.3	24.3	27.3	27.0	(25.3)	24.3	23.5	23.3	23.3	23.8	23.3	22.8	21.3	21.5	21.3	22.3
7	22.8	24.8	27.3	27.3	(25.5)	24.5	23.8	23.5	23.3	24.0	23.8	23.3	23.3	22.0	21.5	22.5
8	22.0	24.0	26.3	26.8	(24.8)	23.5	23.3	22.8	23.0	23.3	23.3	22.8	22.5	21.3	21.0	21.8
9	22.0	23.8	26.0	26.5	(24.5)	23.5	22.8	22.5	23.0	23.3	23.3	22.8	22.3	21.3	21.0	21.8
10	22.0	24.0	26.5	26.8	(25.0)	23.8	23.3	22.8	23.0	23.3	23.3	22.8	22.5	21.3	21.0	21.8
11	22.0	23.5	26.0	26.3	(24.3)	23.3	22.5	22.3	23.3	23.3	23.3	22.8	22.3	21.0	21.0	21.8
12	22.0	23.2	25.8	26.0	(24.3)	23.7	23.1	22.7	22.3	23.3	23.3	22.3	22.3	20.8	20.8	21.5
13	21.0	21.0	22.8	23.3	(22.8)	22.3	22.0	21.3	21.0	21.8	21.8	21.5	21.0	20.0	20.0	20.8
14	20.8	20.5	21.5	22.0	(21.8)	21.5	22.0	21.3	20.8	21.0	21.0	21.0	21.0	19.8	19.8	20.3
15	20.8	20.3	21.0	21.0	(21.0)	21.0	21.0	21.0	20.8	20.8	20.8	20.8	20.8	19.8	19.8	20.3
16	19.8	19.3	19.8	20.0	(20.0)	20.0	20.3	20.0	20.0	19.8	19.8	19.8	19.8	19.0	19.0	19.8

APPENDIX G   Temperature Readings: (°C) 48 hour period. Thermocouple Standard No. 3

DAY	August 11								August 12						August 13	
TIME	09	12	15	18	21	24	03	06	09	12	15	18	21	24	03	06
TC No.																
1	17.3	18.5	21.5	18.5	14.8	13.3	12.8	12.5	19.3	20.0	20.5	17.5	17.3	17.3	17.3	17.0
2	17.8	19.3	22.0	19.0	14.5	13.3	12.5	12.5	19.3	20.3	20.8	17.8	17.0	17.3	17.0	17.0
3	18.8	20.5	22.0	18.8	14.0	12.8	12.3	12.3	19.8	20.5	22.0	17.3	17.0	17.0	17.0	17.0
4	19.0	20.5	22.3	18.8	14.0	12.8	12.0	12.0	20.0	20.8	22.0	17.8	17.0	17.0	17.0	16.8
5	19.0	22.3	23.0	19.0	14.0	13.3	12.3	12.0	19.8	20.8	22.0	17.8	17.3	17.3	17.0	16.8
6	18.8	19.8	22.0	22.3	18.0	16.8	15.5	15.0	18.0	20.8	21.5	19.8	18.8	18.5	18.3	17.8
7	19.8	19.3	21.3	20.5	18.0	16.5	15.5	14.8	19.3	20.0	20.8	19.0	18.3	17.8	17.3	17.0
8	17.0	17.3	19.0	19.8	19.3	18.3	17.5	17.0	16.8	17.8	18.3	18.5	18.3	18.0	17.8	17.3
9	17.0	16.8	17.8	18.3	18.3	18.3	18.3	17.3	17.0	17.0	17.5	17.8	17.8	17.8	17.8	17.3
10	16.5	16.0	16.0	16.0	16.0	16.3	16.3	16.3	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
11	14.0	13.5	14.0	13.8	13.8	14.0	14.0	14.0	13.5	13.8	14.0	13.8	14.0	14.0	14.0	14.0

APPENDIX G   Temperature Readings: (°C) 48 hour period. Thermocouple Standard No. 4

DAY	August 11								August 12						August 13	
TIME	09	12	15	18	21	24	03	06	09	12	15	18	21	24	03	06
TC No.																
1	20.8	20.3	21.5	20.0	14.3	13.3	12.8	12.5	21.5	19.8	20.5	17.5	16.8	17.0	17.0	17.0
2	21.5	23.3	22.0	20.0	14.5	13.3	12.8	12.5	23.3	20.3	20.8	17.8	16.8	17.0	17.0	16.8
3	22.3	29.3	22.3	19.8	14.5	13.3	12.8	12.5	24.5	20.8	21.5	17.8	16.8	17.0	16.8	16.8
4	22.8	29.8	22.8	19.3	14.3	13.0	12.3	12.3	25.5	21.5	22.0	17.8	16.8	16.8	16.8	16.5
5	24.5	30.2	23.5	19.3	14.0	13.0	12.3	12.3	26.0	22.3	23.5	18.3	17.0	16.8	16.5	16.5
6	24.8	30.6	22.3	19.5	15.3	14.8	14.0	14.0	24.8	23.3	24.5	18.8	17.0	16.8	16.5	16.5
7	18.8	19.8	19.8	18.5	16.5	16.0	15.8	15.3	13.3	19.0	19.0	18.0	17.3	16.8	16.5	16.5
8	16.3	17.3	18.3	18.3	17.3	17.0	16.5	16.0	16.3	17.0	17.3	17.3	17.0	16.8	16.5	16.5
9	15.8	16.0	16.5	17.0	16.8	16.8	16.5	16.0	16.0	16.0	16.5	16.3	16.5	16.3	16.3	16.0
10	14.5	14.8	15.0	15.0	14.8	14.8	15.0	14.8	15.0	14.8	15.0	15.0	14.8	14.8	14.8	14.8
11	12.0	12.3	12.5	12.5	12.3	12.3	12.5	12.3	12.5	12.3	12.5	12.3	12.5	12.5	12.5	12.5

APPENDIX H

Mean Temperatures: (°C) First and Second 24 Hour Periods.

Period No. 1: 0900 hours on August 11 - 0600 hours on August.12.

Period No. 2: 0900 hours on August 12 - 0600 hours on August 13.

	TCS-1		TCS-2		TCS-3		TCS-4	
TC No.	P-1	P-2	P-1	P-2	P-1	P-2	P-1	P-2
1	16.5	17.4	16.6	17.8	16.2	18.3	16.9	18.4
2	16.5	17.6	16.6	17.8	16.4	18.3	17.5	18.7
3	16.7	17.8	16.8	17.9	16.4	18.5	18.4	19.0
4	17.1	17.7	17.1	18.0	16.4	18.6	18.3	19.2
5	17.4	18.0	17.4	18.4	16.9	18.6	18.6	19.6
6	24.6	22.3	24.6	22.3	18.6	19.2	19.4	19.8
7	24.8	22.6	24.9	23.0	18.2	18.7	17.6	17.7
8	24.1	22.2	24.1	22.4	18.2	17.9	17.1	16.8
9	24.1	22.2	23.9	22.4	17.8	17.5	16.4	16.2
10	23.8	22.2	24.2	22.4	16.2	16.0	14.8	14.9
11	23.7	22.2	23.7	22.4	13.9	13.9	12.3	12.5
12	23.4	22.0	23.5	22.1				
13	22.2	21.2	22.0	21.0				
14	21.2	20.4	21.4	20.6				
15	20.8	20.2	20.9	20.5				
16	20.8	20.2	20.0	19.6				
17	19.6	19.2						

APPENDIX I

Maximum-Minimum Recording Thermometers: Temperature °C

Four floating units, and one with hygrothermograph (HTG).

SHORELINE	NE		SE		SW		NW			
UNIT No.	No. 1		No. 2		No. 3		No. 4		HTG	
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
June 8	11.1	17.2	11.1	17.2	10.0		11.1	17.2		
15	12.2	16.7	12.2	17.2	12.2	21.1	12.8	18.9	0.5	17.8
22	13.4	17.8	12.8	18.9	12.8	21.1	13.9	21.1	0.0	18.3
29	13.9	20.6	13.4	19.5	14.5	21.1	14.5	21.7	3.9	10.6
July 6	13.4	22.2	13.9	20.6	14.5	21.1			1.7	18.9
13	16.1	26.1	15.6	23.3	13.9	25.0	17.2	25.0	3.9	24.5
20	18.9	27.8	20.0	25.6	19.5	27.8	19.5	24.5	10.0	27.8
27	19.5	27.2	19.5	25.6	17.8	26.7	20.0	27.2	9.4	22.2
Aug. 3	20.0	27.8	19.5	26.1	19.5	28.3	17.8	27.2	12.2	26.1
10	17.8	27.8	19.5	25.6	19.5	28.3	20.0	23.3	11.1	24.5
17	18.9	27.2	18.9	26.1	19.5	27.2	19.5	27.2	9.4	22.5
24	17.8	25.0	17.8	24.5	17.8	25.6	19.5	26.1	7.2	25.0
31	17.8	25.6	19.5	25.0	19.5	26.1	19.5	26.1	10.0	21.1
Sept. 7	17.2	23.9	17.2	23.3	17.2	25.0	17.8	22.5	8.3	21.7
14	13.9	20.6	13.9	19.5	13.9	21.1	13.9	26.7	2.8	18.9
21	13.4	19.5	13.4	17.8	13.9	20.0	13.4	26.1	1.7	19.5
28	10.6	19.5	10.6	17.8	10.0	19.5	10.6	20.0	-0.5	17.8
Oct. 5	9.4	15.0	9.4	13.9	9.4	15.6	9.4	15.0	2.2	15.0
12	7.2	15.0	6.1	14.5	5.6	16.1	6.1	10.6	-2.8	16.7

APPENDIX J

Maximum-Minimum Recording Thermometers: Temperature °C

Weekly mean maximum, mean, and mean minimum temperatures.

Water surface temperature (floating units) only.

DATE	MEAN MINIMUM	MEAN	MEAN MAXIMUM
June 8	11.8	14.5	17.2
15	12.3	15.4	18.5
22	13.2	16.5	19.7
29	14.1	17.4	20.7
July 6	13.9	17.6	21.3
13	15.7	20.3	24.8
20	19.5	23.0	26.4
27	19.2	23.0	26.7
Aug. 3	19.2	23.3	27.4
10	19.2	23.4	27.5
17	19.2	23.1	26.9
24	18.2	21.8	25.4
31	19.1	22.4	25.7
Sept. 7	17.3	20.5	23.7
14	13.9	18.0	22.0
21	13.5	17.2	20.8
28	10.5	14.9	19.2
Oct. 5	9.4	12.2	14.9
12	6.3	10.2	14.1

APPENDIX K

Suggestions for Further Research.

While the temperature represents a basic environmental factor, it is but one of many such factors in a rather complex ecosystem. Many questions remain to be answered, and much research remains to be done, before we can obtain a reasonably sound working knowledge of the subject.

Further study is planned for the Grassy Lake area in the summer of 1970, as additional field equipment and laboratory facilities become available. Included in these plans are the following.

(a) The diurnal and seasonal distribution of oxygen and carbon dioxide in the lake water.

(b) The chemical status of the water, for such materials as the carbonates and sulphates of calcium and magnesium, and the nitrates and phosphates. Analysis for other chemicals will be included.

(c) The chemical and physical analysis of the soils.

(d) The chemical analysis of the precipitation, not only to obtain some idea of the nutrients being brought into the lake, but in connection with a study being conducted by Dr. P. Barclay-Estrup, with regard to the pollution potential of the atmosphere as a result of increased industrialization.

Some questions that remain to be answered with regard to wild rice are listed at the conclusion of that section. There remains the additional 11 Kilograms of seed sewn in Grassy Lake in the fall of 1969. The germination of seed from the 1968 plantings and resultant 1969 crop, and the success of the new plantings, will be of primary importance in the summer of 1970.

BIBLIOGRAPHY

ATKINSON, H. J., GILES, G. R., MacLEAN, A. J. & WRIGHT, J. R. (1958). Chemical Methods of Soil Analysis. Contribution No. 169 (Revised). Canada Department of Agriculture, Ottawa.

BARCLAY -ESTRUP, P. (1966). Interpretation of Cyclical Processes in a Scottish Heath Community. Ph. D. thesis, University of Aberdeen.

BOZNIAK, E. G. & KENNEDY, L. L. (1968). Periodicity and ecology of the phytoplankton in an oligotrophic and eutrophic lake. Can. J. Bot. 46: 1259 - 71.

CASE, F. W. Jr. (1964). Orchids of the Western Great Lakes Region. Cranbrook Institute of Science. Bull. No. 48.

CONARD, H. S. (1956). The Mosses and Liverworts. Revised Edition. Wm. C. Brown Company, Publishers, Dubuque, Iowa.

CURTIS, J. T. & COTTAM, G. (1962). Plant Ecology Workbook. Revised Edition. Burgess Publishing Company, Minneapolis.

DAUBENMIRE, R. F. (1964). Plants and Environment, a Textbook of Plant Ecology. Second Edition. John Wiley & Sons Inc. New York.

ERIKSEN, C. H. (1966). Diurnal limnology of two highly turbid puddles. Verh. int. Verein. theor. angew. Limnol. 16: 507 - 14.

FASSETT, N. C. (1940). A Manual of Aquatic Plants. Revised Edition, E. C. Ogden, 1956. University of Wisconsin Press, Madison.

FERNALD, M. L. (1950). Gray's Manual of Botany. Eighth Edition. American Book Company, New York.

FONDEN, R. (1969). Heterotrophic bacteria in Lake Malaren and Lake Hjalmaren. Oikos. 20: 344 - 83.

FRASER, J. W. (1961). A simple instrument shelter for use in forest ecological studies. Forest Research Branch, Technical Note No. 113. The Queen's Printer, Ottawa.

GEIGER, R. (1961). The Climate Near the Ground. Second Printing. Harvard University Press, Cambridge, Massachusetts.

GOULDER, R. (1969). Interactions between rates of production of a freshwater macrophyte and phytoplankton in a pond. Oikos. 20: 300 -309.

HALE, M. E. Jr. (1961). Lichen Handbook. Second reprint, 1967. Smithsonian Institution Press, Washington, D.C.

HALSTEAD, E. H. & VICARIO, B. T. (1969). Effect of ultrasonics on the germination of wild rice (*Zizania aquatica* L.). Can. J. Bot. 47: 1638 - 40.

HUTCHINSON, G. E. (1957). A Treatise on Limnology. Vol. I. Geography, Physics and Chemistry. John Wiley & Sons Inc., New York.

HUTCHINSON, G. E. (1967). A Treatise on Limnology. Vol. II. Introduction to Lake Biology and Limnoplankton. John Wiley & Sons Inc., New York.

JENNESS, D. (1963). Indians of Canada. National Museum of Canada. Bull. No. 65. Sixth Edition. Queen's Printer, Ottawa.

KERSHAW, K. A. (1964). Quantitative and Dynamic Ecology. Edward Arnold (Publishers) Ltd., London.

LAKELA, O. (1965). A Flora of Northeastern Minnesota. First Edition. University of Minnesota Press, Minneapolis.

McANDREWS, J. H. (1969). Paleobotany of a wild rice lake in Minnesota. Can. J. Bot. 47: 1671 - 79.

MILLER, G. W. & RABE, F. W. (1969). A limnological comparison of two small Idaho reservoirs. Hydrobiologia. 33: 523 - 44.

MOSS, B. (1969). Vertical heterogenity in the water column of Abbot's Pond, I. The distribution of temperature and dissolved oxygen. J. Ecol. 57: 381 - 96.

MOSS, B. (1969). Vertical heterogenity in the water column of Abbot's Pond, II. The influence of physical and chemical conditions on the spacial and temporal distribution of the phytoplankton and of a community of epipelic algae. J. Ecol. 57: 397 - 414.

MOYLE, J. B. (19--). Wild rice - Minnesota's native grain. Bureau of Research and Planning. Minnesota Department of Conservation. Minneapolis.

MOYLE, J. B. (1967). Wild rice - some notes, comments, and problems. Special Publication No. 47. Division of Game & Fish, Minnesota Department of Conservation, Minneapolis.

MOYLE, J. B. & KRUEGER, P. (1964). Wild rice in Minnesota. Special Publication No. 18. Division of Game & Fish, Minnesota Department of Conservation, Minneapolis.

NEILSON, J. D. (1964). Wild Rice Identification and Propagation in Northern Saskatchewan. Department of Agriculture, Province of Saskatchewan.

ODUM, E. P. (1959). Fundamentals of Ecology. Second Edition. W. B. Saunders Company, Philadelphia.

PHILLIPS, E. A. (1959). Methods of Vegetation Study. Henry Holt & Co., Inc.

PLATT, R. B. & GRIFFITHS, J. F. (1964). Environmental Measurement and Interpretation. Reinhold Books in Biological Sciences. Reinhold Publishing Corporation, New York.

PYE, E. G. (1962). Geology and Scenery Along the North Shore of Lake Superior. Ontario Department of Mines, Geological Circular 10, Department of Mines, Toronto.

REID, G. K. (1961). Ecology of Inland Waters and Estuaries. Reinhold Book Corporation, New York.

REID, L. A. G. (1967). Chemical, Physical, and Biological Characteristics of Lake Ashtabula Reservoir in Southeastern North Dakota. M.Sc. thesis. North Dakota State University.

ROGOSIN, A. (1951). An Ecological History of Wild Rice. Division of Game & Fish, Minnesota Department of Conservation, Minneapolis.

RUTTNER, F. (1963). Fundamentals of Limnology. Third Edition. Translated by D. G. Frey and F. E. Fry. University of Toronto Press.

SCOGGAN, H. J. (1957). Flora of Manitoba. National Museum of Canada Bull. No. 140. Department of Northern Affairs & National Resources, Ottawa.

SCULTHORPE, C. D. (1967). The Biology of Aquatic Vascular Plants. First Edition. Edward Arnold (Publishers) Limited, London.

SIMPSON, G. M. (1966). A study of germination in the seed of wild rice (Zizania aquatica L.). Can. J. Bot. 44: 1 - 9.

SPENCE, D. H. N. (1967). Factors controlling the distribution of fresh-water macrophytes with particular reference to the lochs of Scotland. J. Ecol. 55: 147 - 70.

STEEVES, T. A. (1952). Wild rice - Indian food and a modern delicacy. Econ. Bot. 6: 107 - 42.

STODDARD, C. H. (1957). Utilization of swamplands for wild rice production: a progress report. Journal of Soil & Water Conservation. 12: 135 - 38.

THOMAS, A. G. & STEWART, J. M. (1969). The effect of different water depths on the growth of wild rice. Can. J. Bot. 47: 1525 -31.

TRYON, R. M. Jr. (1954). The Ferns and Fern Allies of Minnesota. University of Minnesota Press, Minneapolis

WEBER, R. P. & SIMPSON, G. M. (1967). Influence of water on wild rice (Zizania aquatica L.) grown in prairie soil. Can. J. Plant Sc. 47: 657 -63.

WETZEL, R. G. (1964). Primary productivity of aquatic macrophytes. Verh. int. Verein. theor. angew. Limnol. 15:426 - 36.

VICARIO, B. T. & HALSTEAD, E. H. (1967). A progress report on wild rice research. Unpublished report. Department of Soil Science, University of Saskatchewan, Saskatoon.