THE RELATIONSHIP BETWEEN EVAPOTRANSPIRATION BY *PHRAGMITES COMMUNIS* TRIN. AND WATER TABLE FLUCTUATIONS IN THE DELTA MARSH, MANITOBA

by

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ABSTRACT

Evapotranspiration by *Phragmites communis* Trin. var. *berlandieri* (Fourn.) Fern. in the Delta Marsh of Manitoba, Canada was measured with small hydraulic load cell lysimeters [after Hanks and Shawcroft, 1965]. The measurements were recorded in two stands, available moisture being greater at Site A than Site B. Site A had a lower leaf area index than Site B. The major portion of the data was collected in the summers of 1970 and 1971. An evaporation lysimeter, operating in conjunction with the others, enabled a separation of evapotranspiration into its evaporation and transpiration components. Lysimeter transpiration was transposed to stand transpiration according to the ratio of leaf area of the lysimeters to leaf area index of the stand.

Mean daily evapotranspiration rates were highest in July. Transpiration accounted for 75 to 80 percent of evapotranspiration at Site A and 85 to 90 percent at Site B when the *Phragmites* canopy was fully developed. June percentages were lower especially at Site A (53.9 %). Transpiration per unit leaf area was higher in June and September (>30 ml dm^{-2}) than during July and August (0-20 ml dm^{-2}). Explanations for this are based on direct and indirect effects of leaf development and senescence.

Total evapotranspiration for the 1971 season, June 1 to September 10, was estimated to be 307.8 mm at Site A and 304.7 mm at Site B, almost double the effective precipitation for the same period. The ecological implications of this are discussed.

Estimates of evapotranspirational consumption of groundwater were obtained by an analysis of water table fluctuations [White, 1932]. Poor correlations were obtained between this estimate and actual evapotranspiration when all available data were used. The direct effect of rainfall on the water table and the possibility that the assumed specific yield of the soil may have been incorrect are presented to explain the poor quality of the estimate. The effect of rain was minimized by choosing a period when no rain fell. Although the estimate, based on water table fluctuations then showed a strong dependence on water table depth, a direct correlation with evapotranspiration was suggested.

The relationship between selected meteorological parameters and evapotranspiration was determined by simple and multiple linear regression analysis. Simple correlations between evapotranspiration and incoming short-wave radiation, net radiation, and relative humidity were all significant ($p < 0.01$). The simple correlations between evapotranspiration and wind were not significant while those between evapotranspiration and temperature were only significant in 1970. Multiple correlation coefficients, $r = 0.80$ to 0.90 were significant at $p < 0.01$. Regression coefficients for the temperature and wind terms in the equations were not significant but those on short-wave radiation, net radiation and relative humidity were highly significant ($p < 0.01$). Better correlations were obtained when net radiation replaced short-wave radiation in the analyses.

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CHAPTER I

INTRODUCTION

CHAPTER I

INTRODUCTION

A. Statement of Problem

This project set out to determine whether evapotranspiration by *Phragmites communis* var. *berlandieri*,[1] a major dominant in the Delta Marsh, Manitoba, Canada, was the cause of the duirnal fluctuations in the shallow ground water table. Interest in this problem was aroused by the observation of diurnal fluctuations in the shallow ground water table beneath plant communities in the marsh [Gilliland, 1965]. Inherent in this primary objective was the interest in describing the daily, monthly and seasonal water requirements of *Phragmites*, data which have not been determined to date in North America. The final objective was to define the relationships between evapotranspiration and selected meteorological parameters; incoming short-wave radiation, net radiation, temperature, windspeed and relative humidity, information, which is relevant to marsh management and conservation programs.

B. Literature Review

Evapotranspiration is a major process in the hydrological cycle [Gray, ed., 1970, p. 3.1] in that it transfers water molecules

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[1] The nomenclature throughout this thesis follows Scoggan [1957] after Fernald [1950] and Gleason [1952].

from land and water surfaces to the atmosphere to be returned to the earth by precipitation, dew or fog.

Of the definitions for evapotranspiration which have appeared in the literature, that by Van Bavel [1961, p. 138] is the most comprehensive. He defines evapotranspiration as "the process of movement of water from the earth's land surface to the atmosphere in vapor form" and to include "evaporation from the surface of the soil and plant as well as transpiration of water by leaves and the net flow of water vapor across the liquid-air interface in the free pore space of the soil."

Evaporation affects the energy budget by dissipating a portion of the radiant energy which filters through the plant canopy. If the surface is moist, a large proportion of the radiant energy will be converted to the latent heat of vaporization and very little heating will occur. On the other hand, if the surface is dry and resistant to evaporation, a greater proportion of the energy will be converted to sensible heat at the soil surface and in the air close to it [Tanner and Lemon, 1962; Aase and Wight, 1970]. The volume of water lost by evaporation can exceed 20 percent of the total evapotranspiration in wet habitats [Gel'bukh, 1964], but is much less (10%) in drier sites [Begg *et al.*, 1964]. Therefore, the effect of evaporation on the water balance of an area is significant.

Transpiration involves the diffusion of water vapor through open stomata in the leaves, and the movement of water molecules through the cuticular layer of plant surfaces. Stomatal transpiration is greater than cuticular because the resistance to vapor movement is lower [Holmgren *et al.*, 1965]. Open stomata allow water vapor, which has evaporated from the moist surfaces of the palisade and mesophyll cells in the leaf to diffuse into the atmosphere surrounding it. The stomata must be open to allow carbon dioxide to diffuse into the leaf and therefore, the plant cannot avoid losing water [Teal and Kawanisher, 1970].

It is known that transpiration cools the leaves of plants [Waggoner and Zelitch, 1965] but Teal and Kawanisher [1970] found that the leaf temperature was closely coupled with air temperature in *Spartina* spp. and probably in other grasses. Kramer [1969] observed that leaf temperatures do not rise to a lethal level in the absence of transpiration. It has also been suggested that transpiration is beneficial to the plant in providing a transport stream for the distribution to the various plant organs of mineral elements absorbed by the roots [Clements, 1934]. Kramer [1969] refutes this by noting the healthy growth of plants in humid environments where the transpiration rate is low. If transpiration exceeds the available supply of water in the soil or the ability of the roots to absorb it, water deficits occur causing leaves to wilt and stomata to close [Yemm and Willis, 1954]. This slows the carbon dioxide exchange between the atmosphere and the leaves and ultimately reduces the plant productivity [Brix, 1962]. Serious wilting can also be physically damaging to the plant tissues [Kramer, 1969].

Evapotranspiration rates of *Phragmites* growing in other parts of the world have been reported by Kiendl [1953], Gel'bukh [1964], Rudescu *et al.* [1965], Haslam [1970], Królikowska [1971], Burian [1971], Rychnovská and Smíd [1973]. The majority of these authors were studying the water use of *Phragmites* to quantify its effect on the water balance of overgrown reservoirs.

Kiendl [1953] using a rapid weighing method found that transpiration from dense stands exceeded the annual rainfall. He estimated that ET could be as high as 1500 mm H_2O per year in dense stands with a long growing season but as low as 500 mm where stands are sparse and the growing season short.

Gel'bukh [1964] determined evapotranspiration rates of *Phragmites* from observations of water loss from evaporimeters containing transplanted clones of reeds. Evapotranspiration was 0.8 to 2.5 times as great as from a free-water surface, daily rates ranging from 2.0 to 11.8 mm day^{-1} at the mid-summer peak and between 440 and 1700 mm for the vegetation season.

Rudescu *et al.* [1965] recorded similar rates of evapotranspiration, with a daily average consumption of 6.0 mm-day for the eight year study and an average loss of 630.6 mm during the experimental period of 105 days. Extrapolating to a growing period of 214 days they estimated up to 1500 mm could be used per year, 2-3 times greater than precipitation.

Haslam [1970] indicates that the results from pilot evapotranspiration tests which she conducted in East Anglia agreed with the annual evapotranspiration rates presented by Kiendl [1953] and Rudescu *et al.* [1965]. Thus, annual water consumption fell in the 1000 to 1500 mm range.

The last three studies to be cited used a rapid weighing technique whereby plant material (either leaves or the whole shoot) was removed from the stand weighed, returned to the stand for a 3-10 minutes then weighed again [Królikowska, 1971; Burian, 1971; Rychnovská and Smíd, 1973]. Królikowska [1971] recorded average daily transpiration of 2.23 mm day^{-1} over the vegetation season. He also compared transpiration from terrestrial stands and those growing in water finding that it was 60 percent less in plants growing on land. Burian [1973] estimated water consumption over a period of 190 days to be 100 mm almost 1/3 of the total being lost in July with a daily mean of 10 mm day^{-1}. Rychnovská and Smíd [1973] reported results from a preliminary study indicating that water use was primarily dependent on the LAI. The stand having a LAI of 4.7 showed a daily loss of 11.37 mm while water consumption in one with a LAI of 3.4 was only 6.88 mm day^{-1}.

In all cases, stand density and variations in environmental conditions were cited as the predominant contributors to the variability in water loss recorded on a daily basis between *Phragmites* stands. The length of the growing season was a significant factor in the differences in annual evapotranspirational losses.

Evapotranspiration by other wetland emergents has also been studied. Blaney [1956] examined evapotranspiration from tules (*Scirpus* spp) and saltgrass (*Distichlis* spp) with a view to minimizing evaporation from overgrowing reservoirs. Migahid, quoted by Penman [1963] and Rijks [1969], examined evapotranspiration rates of papyrus (*Cyperus papyrus*) to compare transpirational losses to evaporation from an open lagoon. Linacre *et al.* [1970] adopted the same objective in an Australian swamp overgrown with three species of *Typha*. Eisenlohr [1966], Shjeflo [1968] and Evans [1971] examined evapotranspiration as a component in the water balance. Eisenlohr [1966] and Shjeflo [1968] were studying evapotranspiration from prairie potholes containing bulrushes (*Scirpus acutus*) cat-tails (*Typha angustifolia, T. glauca* and *T. latifolia*) and whitetop (*Scholochloa festucacea*) while Evans [1971] observed the evapotranspiration from a domestic rice paddy.

Many methods have been employed to measure evapotranspiration, some providing direct measurements and some indirect. When direct measurements are made, the soil in which the plants are growing must be isolated from the surroundings in an evaporimeter or lysimeter. Gel'bukh [1964] and Rudescu *et al.* [1965] transplanted soil monoliths from *Phragmites* stands into water-proof containers. Water covered the soil surface at all times and the amount of water required to maintain the level was equated with evapotranspiration. The same method was used to measure evapotranspiration from tules (*Scirpus* spp.)[Blaney & Muckel, 1955] and rice [Evans, 1971]. Others monitored the amount of water required to maintain a constant water table within lysimeters [Gatewood *et al.*, 1950; Penman, 1948 and Mather, 1954]. The above methods are only applicable when studying evapotranspiration rates from plants which are normally flooded or grow in soils with a shallow ground water table.

Percolation or drainage lysimeters [Gilbert and Van Bavel, 1954; Van Bavel and Harris, 1961; and Davenport, 1967] measure evapotranspiration by equating it to differences between the precipitation or irrigation volume and drainage. However, these measurements are only accurate for seasonal or annual E_T determination because of the time lag involved in seepage and soil moisture profile development [Van Bavel, 1961].

Courtin and Bliss [1971] agree with Van Bavel [1961, p. 139] that "in order to obtain accurate values of evapotranspiration over periods of a day or less, lysimeters must be weighed." Various weighing devices have been used including a simple balance to weigh small pots [Mooney *et al.*, 1965], a beam balance to weigh larger tanks [Wilcox,1965] and a sophisticated counterbalance and electronic load sensor system for very heavy lysimeters [Libby and Nixon, 1963]. In recent years, floating lysimeters employing Archimedes' principle and hydraulic load cell lysimeters making use of Darcy's law have become popular [King *et al.*, 1956; Harrold and Dreibelbis, 1958; Pruit and Angus, 1960; Graham and King, 1961; King *et al.*, 1965; Fulton and Findlay, 1966; Pelton, 1969] A floating lysimeter is one in which the inside tank (with soil and growing plants) floats in a liquid (water, zinc chloride solution, etc.) enclosed by a slightly larger container. The volume of liquid displaced by the inside container is measured and the weight of the lysimeter calculated according to the density of the liquid. In a hydraulic load cell lysimeter the inside container is supported on a liquid filled bolster (flexible walled container). The pressure created within the bolster is a function of the weight of the inside container and can be measured by a manometer or pressure gauge.

Black *et al.* [1968] reviewed the research in hydraulic load cell lysimeters, citing the use of various types of rubber, plastic or stainless steel bolsters filled with liquid and connected to a stand pipe to support the mass of the lysimeter. Large lysimeters of this type have been used by Ekern [1958], Hanks and Shawcroft [1965] and Black *et al.* [1968], but evapotranspiration rates have also been measured with small hydrostatic lysimeters [Courtin and Bliss, 1971].

A number of equations have been developed to provide indirect estimates of evaporation and/or evapotranspiration. These use meteorological parameters and provide a means of calculating energy exchange or transfer processes. Penman's formula, originally proposed in 1948 is probably the most popular empirical formula. It tends to be universally applicable because it includes the four environmental parameters radiant energy, temperature, wind speed and vapour pressure deficits, known to affect the evaporative potential of air. Other individuals have proposed formulas based on combinations of only some of these parameters. A mean temperature and day length formula was used by Thornthwaite [1948] and mass-transfer formulas based on vapour pressures and wind speed were proposed by Meyer [1942] and Harbeck [1962]. The mass-transfer formula [Harbeck, 1962] in combination with a water budget analysis was used to compute the evapotranspiration from vegetated potholes in North Dakota [Eisenlohr, 1966; Shjeflo, 1968]. Linacre *et al.* [1970] estimated evapotranspiration from an Australian swamp by considering the eddy fluxes of sensible and latent heat from a surface.

Although these formulas are theoretically sound and good correlations were achieved with their use, they are only valid for the environmental regime under which they were defined. As a result, some investigators have used correlational methods (e.g. simple linear or curvilinear regressions and multiple linear regressions) to define the relationships between local climatic conditions and evaporation or evapotranspiration rates. Excellent correlations were found between evapotranspiration and net radiation [Tanner and Pelton, 1960; Graham and King, 1961], while others have examined the simple relationships between evapotranspiration and parameters such as incoming solar radiation, net radiation, various measurements of temperature, vapour pressure deficits, relative humidity, dew point temperatures, and wind run [Wilcox, 1963; Hobbs and Krogman, 1966; Davenport, 1967 and Evans, 1971]. In all cases either temperature or radiant energy were most closely correlated with evapotranspiration. This is to be expected because energy in the form of heat or light is necessary to provide the latent heat of vaporization. Multiple linear regressions to evaluate the combined effects of various environmental factors on evaporation or evapotranspiration have also been computed [Baier and Robertson, 1965; Hobbs and Krogman, 1966; Davenport, 1967 and Evans, 1971]. All found that solar energy or temperature are the most important parameters governing the rate of the processes.

Another indirect estimate of consumptive use (evapotranspiration plus water retained in plant cells and tissues) can be made on a basis of the diurnal fluctuations in the shallow ground water table. White [1932] developed a formula based on the assumption that the drawdown of the water table during the daylight hours is caused by the rate of evapotranspiration exceeding the rate of ground water recharge. Because evapotranspiration rates are generally low at night, the average recharge rate can be approximated by the rate of rise of the water table at night. The 24 hour recharge plus the net drop in the water table per day then equals the evapotranspiration. In spite of the fact that other factors besides evapotranspiration cause fluctuations in the water table this method has been used with a degree of success to evaluate evapotranspiration by phreatophytes Meyboom [1967].

C. Description of the Study Area

This research was conducted in the Delta Marsh, (50°11'N.Lat.; 98°23'W.Long.) Manitoba, Canada, which skirts the southern shore of Lake Manitoba, and covers an area of 15,000 hectares (Figure 1). Walker [1965, p. 16] provided a comprehensive description of the physiography, geology and setting of the marsh and Ehrlich *et al.* [1957] described the soils in detail.

The fertile agricultural plain to the south of the marsh has developed on lake bed and flood plain deposits (clayey). In the marsh, glacial till deposits have been covered with a layer of undifferentiated muck and peat [Ehrlich *et al.*, 1957] up to 30 cm thick [Walker, 1965].

The climate of this region is continental with high summer and low winter temperatures. The winter months, November through March

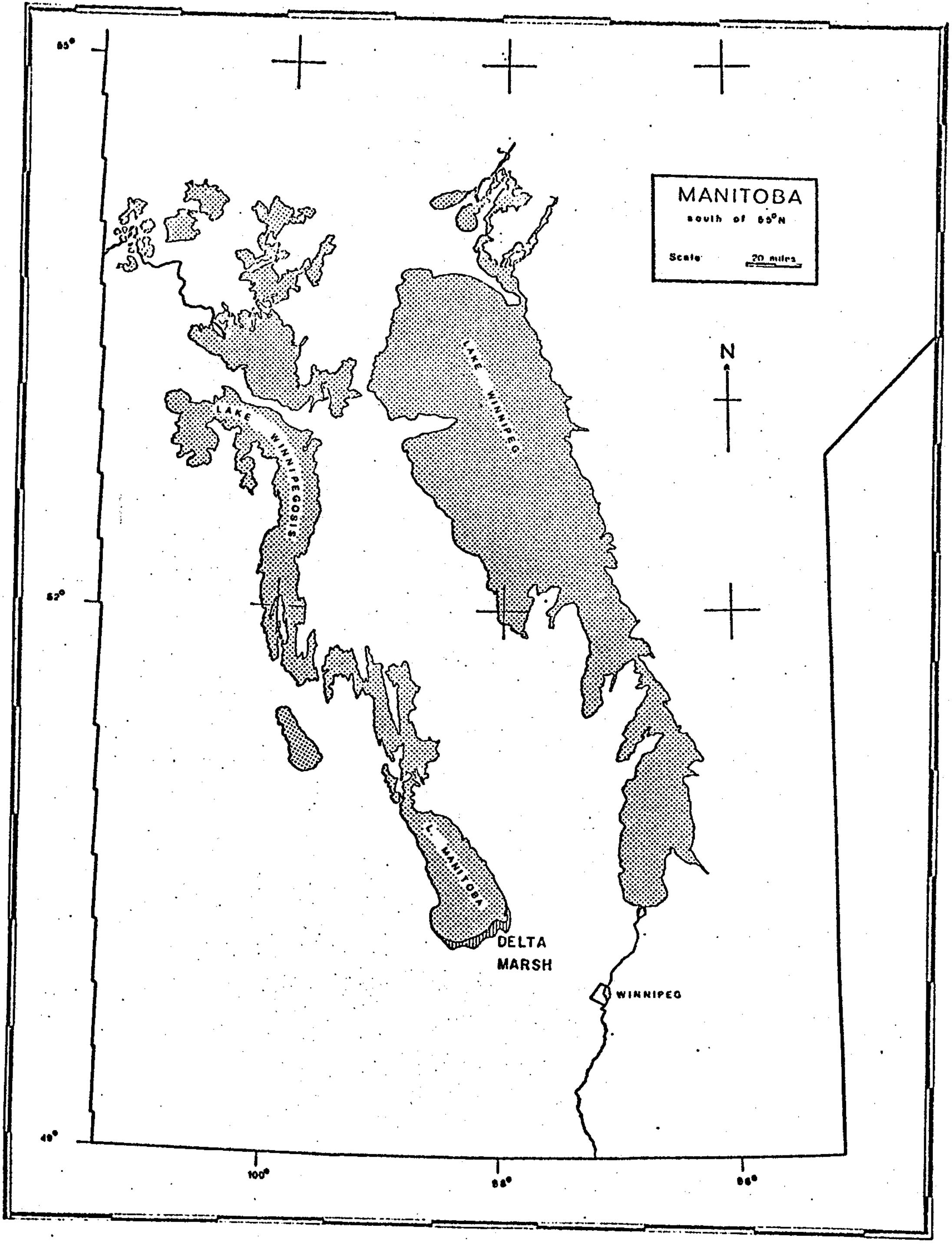

Figure 1 Map of southern Manitoba showing location of the Delta Marsh

inclusive, have a mean temperature below 0°C (32°F) and from May to September the mean temperature is above 10°C (50°F).

The area lies on the western fringe of the sub-humid moisture region [Weir, 1960] and has a mean annual precipitation of 52.07 cm (20.5 in.). Hydrologically, the Delta Marsh is a discharge area for the lands lying north of the Assiniboine River [Meyboom, 1962].

On the basis of the most recent vegetation survey of the marsh [Walker-Shay, personal communication, 1972], *Phragmites communis* was shown to be an important emergent, colonizing 14.7 percent of the total marsh area.

Two sites, A and B were chosen in the marsh (Figure 2), important considerations for the selection being plant composition, water regime and accessibility. Stands of *Phragmites* which had relatively few understory individuals were sought so the effect of associated plants would be minimized. Understory species increase soil shading, alter the energy budget within the canopy and draw moisture from the soil. Examination of the effects of the understory plants on evapotranspiration by the stand was beyond the scope of this study. *Phragmites* stands occupying a wet and a dry site were chosen so the results would represent a cross section of all the communities in the marsh. *Phragmites* at Delta will colonize areas where the water depth does not exceed 50 cm and non-flooded sites where their roots can reach the ground water [Walker, 1965]. Proximity to access roads was an important consideration since readings as nearly simultaneous as possible were required and a distance of 2.4 km separated the two sites.

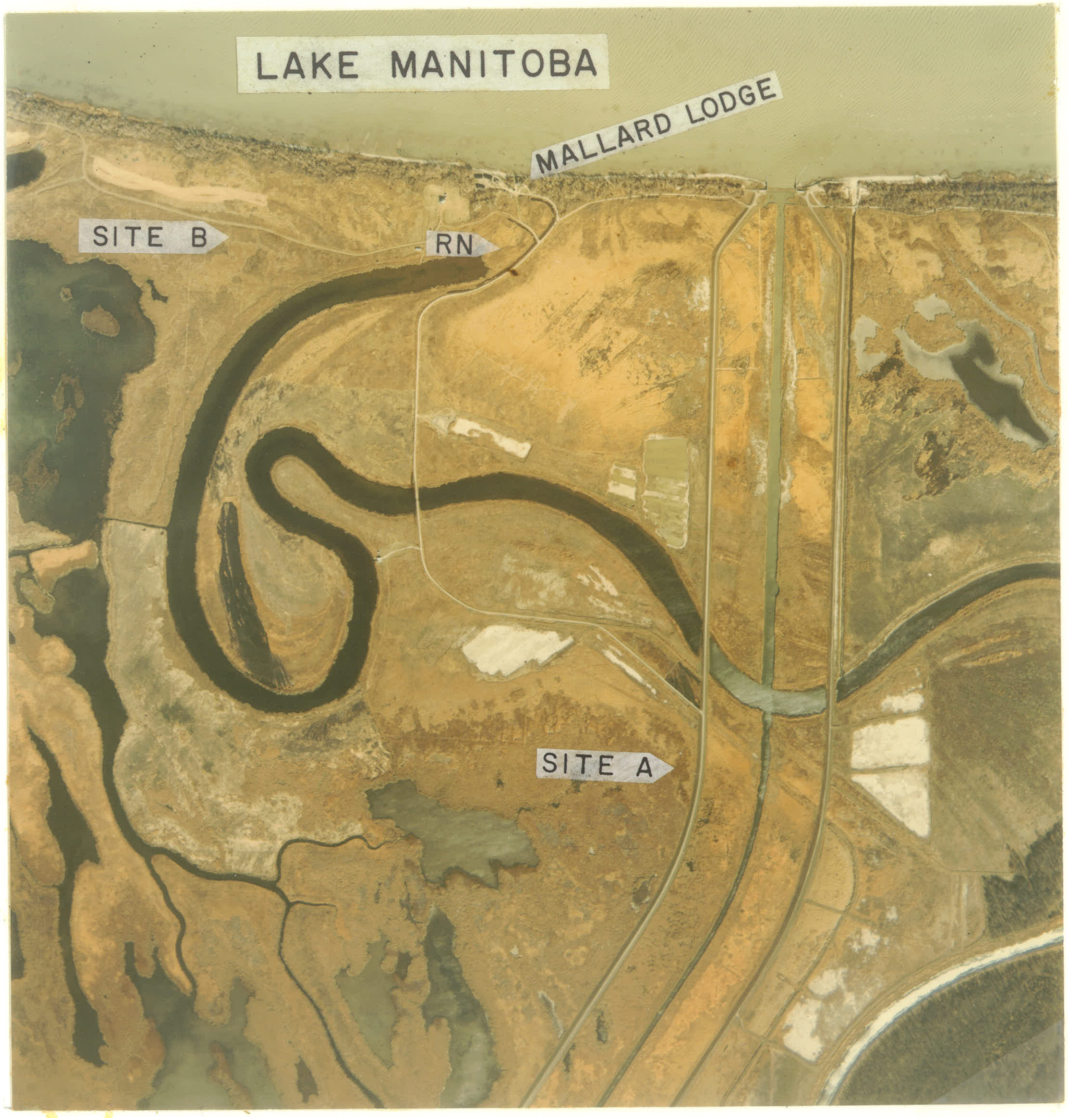

Figure 2 Aerial photograph of the study area showing location of Site A, Site B, Mallard Lodge and the Net Radiometer (R_N)

Site A (Figure 3) was located at the base of the west dyke of the Assiniboine Diversion, on the outside of the channel, about 1.9 km south of the lakeshore. It was chosen because of the proximity to observation wells installed by Gilliland[1] and his co-workers where diurnal fluctuations in the water table had been observed [Gilliland, 1965]. It had a water regime in the moist part of the normal range for *Phragmites* in this marsh. In the spring this site is flooded to a depth of 10 to 15 cm and during the summer the water table drops to approximately -40 cm. Site A was dominated by *Phragmites* and had an understory of *Lycopus asper, Teucrium occidentale, Chenopodium rubrum* and an occasional clone of *Carex atherodes*. The total density of understory species was 34.9 plants m^{-2} in 1970 and 51.5 plants m^{-2} in 1971.

Site B (Figure 4) was located on the Portage Country Club property approximately 800 m west of Mallard Lodge and 350 m south of the lakeshore. This site approached the drier moisture limit for *Phragmites*. The water table was near the soil surface in May but dropped to -100 cm below the surface during the summer. The understory species included *Stachys palustris, Lycopus asper, Teucrium occidentale, Mentha arvensis, Cirsium arvense, Urtica dioica* and *Chenopodium rubrum*. This density was 33 plants m^{-2} in 1970 and 46.9 plants m^{-2} in 1971. There was no evidence that either site had been disturbed by man in recent years.

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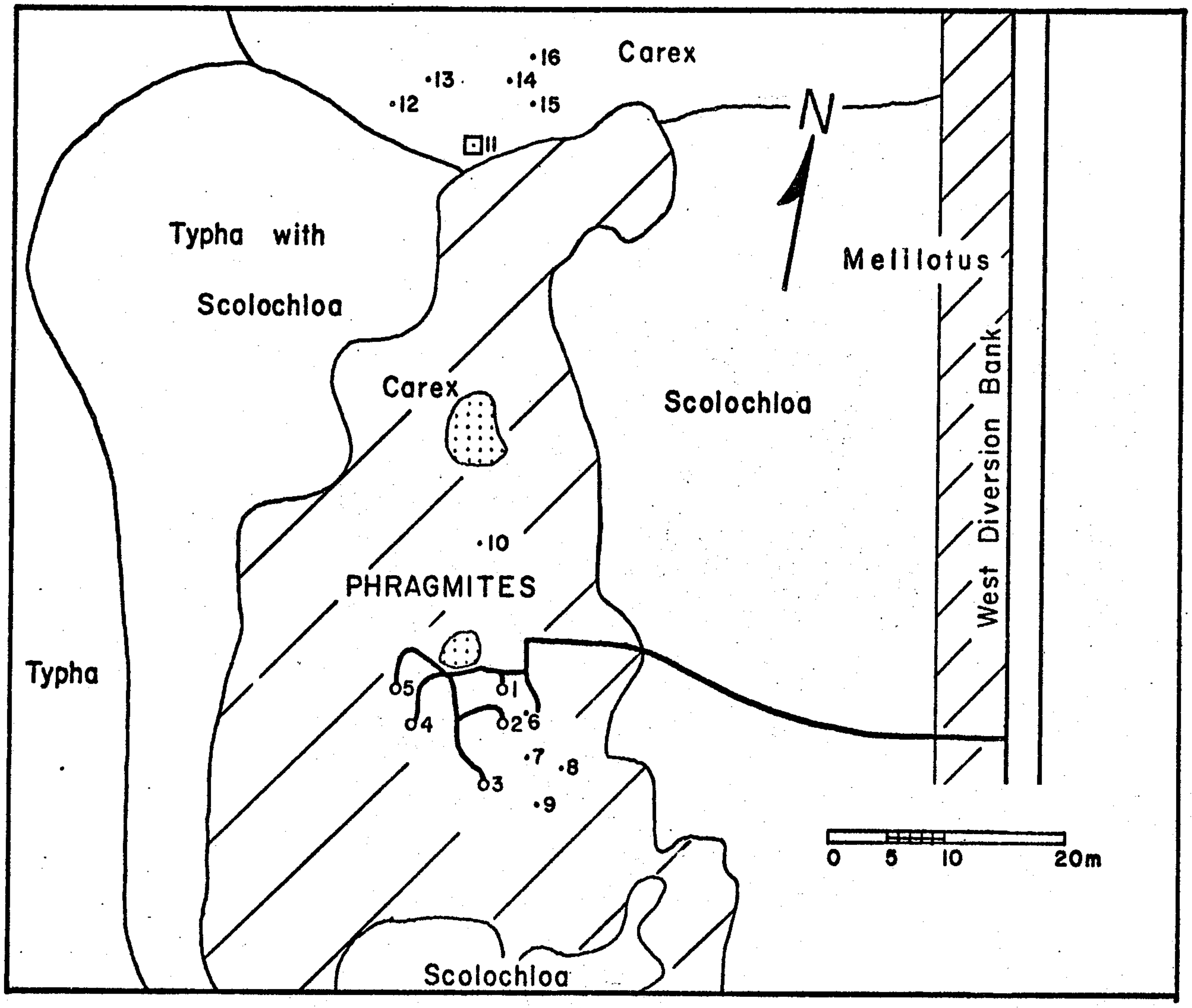
[1] Ground Water Section, Hydrologic Sciences Division, Inland Waters Branch, Department of Energy, Mines & Resources, Ottawa, Canada.

1. Evaporation Lysimeter
2. Control Lysimeter
3.
4. Green Lysimeters
5.
6. Temperature profile
7. Anemometer
8. Pyrheliograph at 50 cm
9. Hygrothermograph at 1 m
10. Observation well (A5)
11. White storage shed
12. Observation well (A4)
13. Pyrheliograph at 3 m
14. Tipping bucket rain gauge
15. Observation well (A2)
16. Temperature sensor for Stevens A35 Recorder

Figure 3 Map of Site A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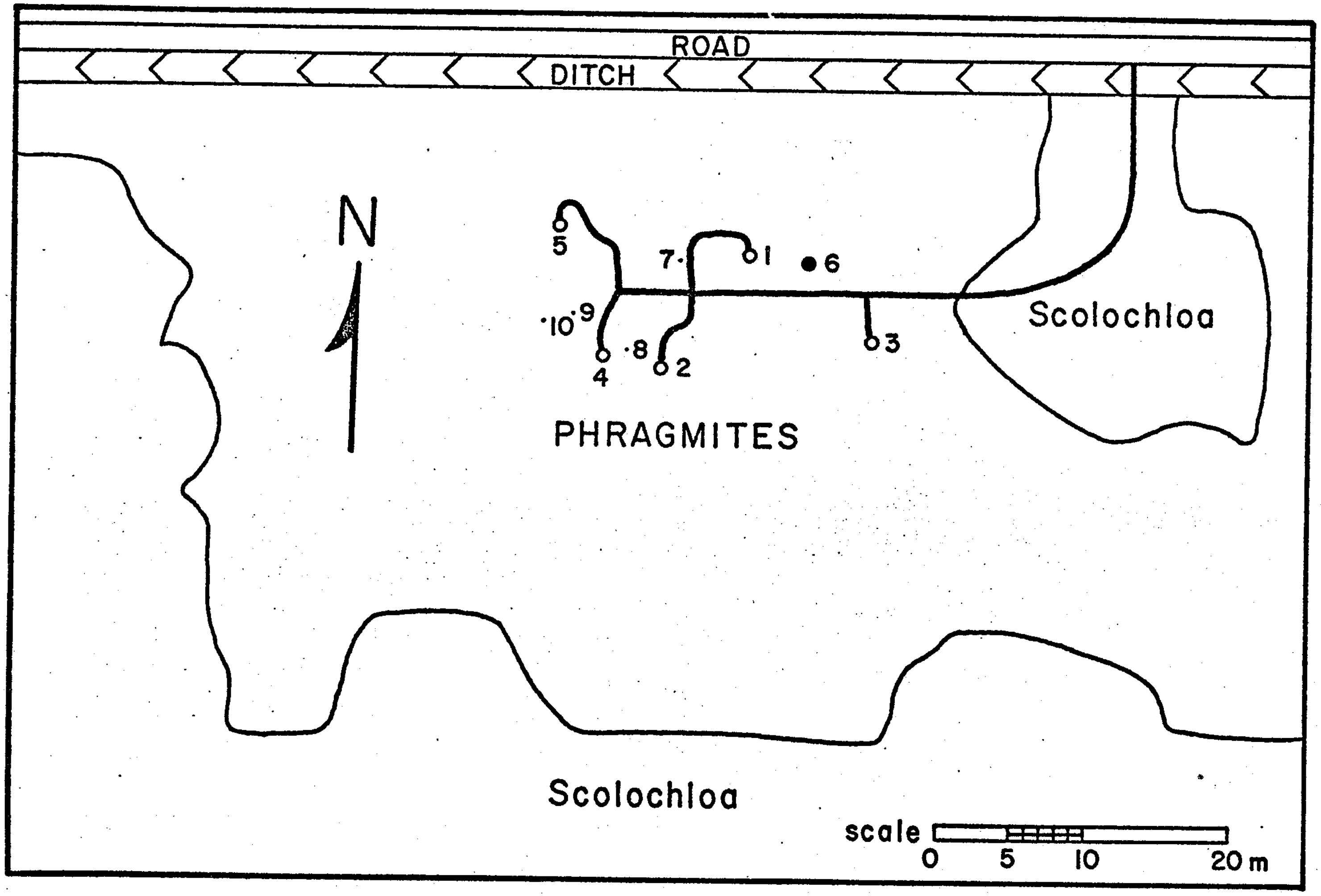
SITE A

1. Control Lysimeter
2. Evaporation Lysimeter
3.
4. } Green Lysimeters
5.
6. Observation Well (B4)
7. Temperature Profile
8. Hygrothermograph
9. Pyrheliograph at 50 cm
10. 3-cup Anemometer

Figure 4 Map of Site B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SITE B

CHAPTER II

METHODS

A. Measurement of Environmental Parameters

1. Incoming Shortwave Radiation

Incoming shortwave radiation (R_I) (0.36 to 2.0 microns) was measured with a Belfort pyrheliograph (Figure 5) mounted at a height of 3 m in the zone of *Carex atherodes* 10 m north of the *Phragmites* stand at Site A (Figure 3). This instrument only receives incident radiation from above and the only necessary mounting condition was that it not be shaded. It has a sensitivity of 0.1 gm cal cm^{-2} min^{-1} and an accuracy of ±5 percent; the borosicate glass dome had a transmission coefficient of 90 percent for 0.36 to 2.0 microns. The null reading of the instrument was adjusted in an unlit laboratory area on a weekly schedule. To prevent moisture droplets from collecting in the glass dome, a tray of silica gel desiccant was placed inside the instrument housing and replaced weekly. The glass dome was cleaned periodically by rinsing it with distilled water; it was dried with a lint-free cloth. The instrument was in operation from June 4th to October 6th, 1970, and from May 1st to September 14th, 1971, the data being recorded on a weekly chart.

The area below the curve on the chart was measured with a polar planimeter and converted to gm cal $cm^{-2}min^{-1}$ according to the formula:

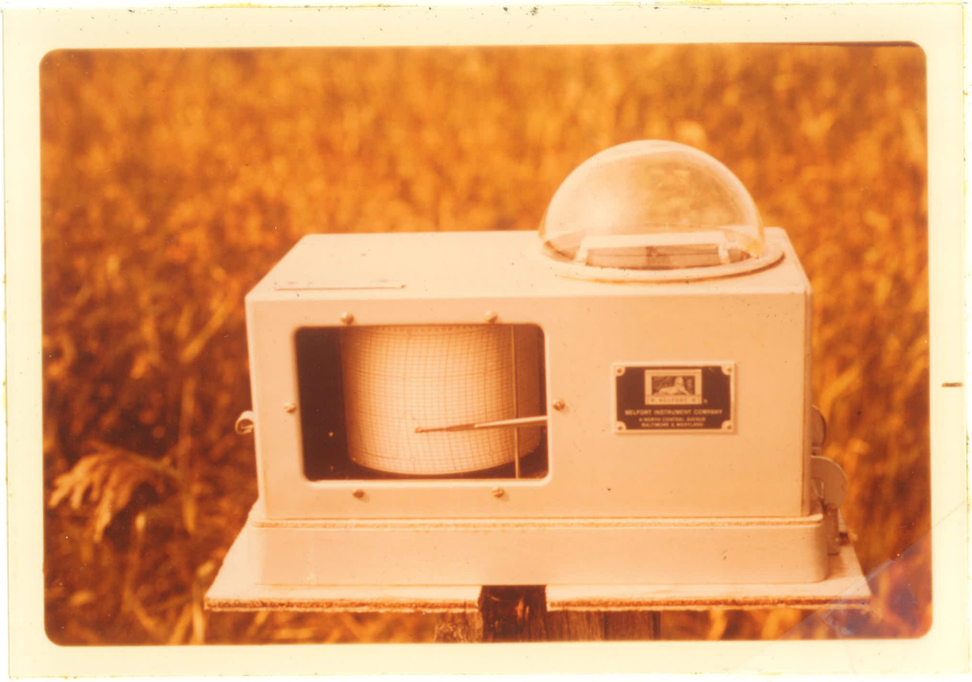

Figure 5 Pyrheliograph

$$\frac{X}{Y} \times 1440 \text{ min day } -1 \times 3 \text{ gm cal cm}^{-2}\text{min}^{-1}$$

(Instruction Manual #11900 Belfort Inst. Co.)

where

X = measured area under the daily trace

Y = area (cm^2) on the chart had 3 gm cal $cm^{-2}min^{-1}$ been received for 24 hours.

All energy values were converted to mm H_2O equivalents to correspond with the units used to express evapotranspiration rates. The formula derived for this conversion was:

$$R_I(\text{mm } H_2O) = \frac{10\ R_I(\text{gm cal cm}^{-2}\text{day}^{-1})}{H_V} \quad \ldots .(1)$$

where

H_V = heat of vaporization of water (gm cal gm^{-1})

It is based on the fact that 1 gm of water is equivalent to 1 cm^3 or 10 mm depth over an area of 1 cm^2. Therefore the energy required to evaporate 1 gm of water is equivalent to the energy required to evaporate 10 mm of water. The relationship between the heat of vaporization and ambient temperature was obtained by simple linear regression from data in the Handbook of Chemistry and Physics, [Hodgman, 1960, p. 2418].

$$H_v = 595.9 - 0.5475\ T°C$$

where

T°C = mean daytime air temperature obtained at a height of 1 m in the *Phragmites* stand.

The daily data were presented in graphical form and the mean daily incoming radiation for each month computed. The data from Site A were used at Site B since the sites were only 2.4 km apart.

2. Net Radiation

Net radiation (R_N) in the wavelength range of 0.2 to 50 microns was measured with a CSIRO model SRI4 net radiometer (Figure 6) recording on a Honeywell model 194 recorder equipped with a DISC integrator. The instrument had a sensitivity of 0.017 cal $cm^{-2}min^{-1}$ at 20°C with an accuracy of ±2.5 percent and a recorder accuracy of ±0.15 percent of full scale. It was mounted 3 m above a *Phragmites* stand 130 m south of the field station lodge (Figure 2). It could not be located at either of the sites because they could not be serviced with a 110 volt power supply necessary for the recorder. The stand over which it was mounted had a density and height similar to the study sites.

The polyethylene hemispheres were inflated with air pre-dried by passing it through a container of silica gel crystals. The rate of air movement was greater than 20 bubbles per minute and the desiccant was changed at weekly intervals. The hemispheres were cleaned or replaced as required and the recorder was calibrated regularly.

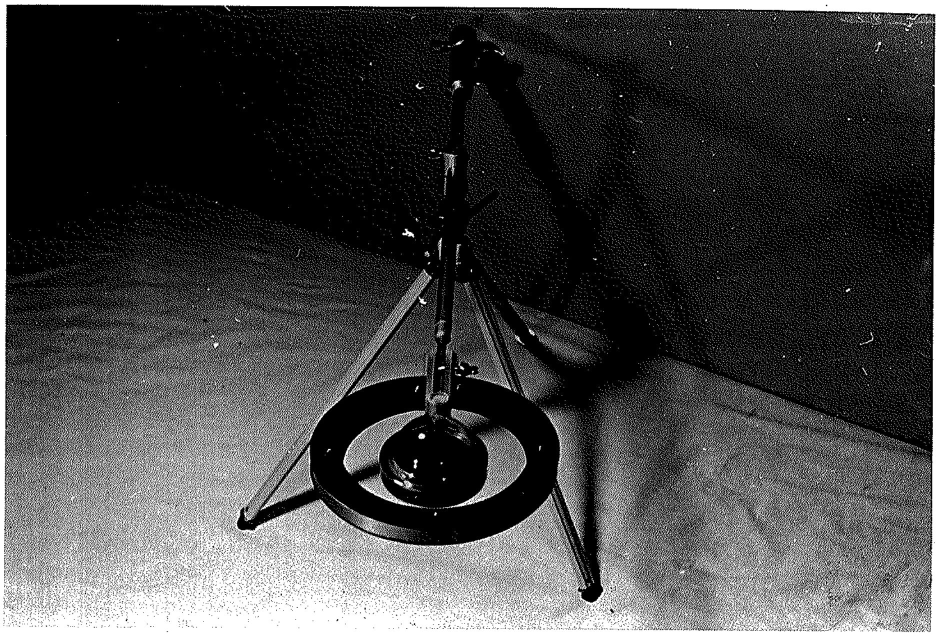

Figure 6   Net radiometer

The instrument was in operation from June 16th to September 10th, 1971. Funds were not available for the purchase of this equipment in 1970 and an electronic defect in the recorder prevented an earlier start in 1971. To reduce the analysis time, the integrated total daytime (sunrise to sunset) net radiation was determined only on the days for which evapotranspiration data were available. The daily values were converted to mm H_2O equiv. using formula (1) and then plotted in graphical form. The relationship between this parameter and incoming short-wave radiation was determined by linear regression analysis.

3. Temperature

(a) Thermograph

A Belfort hygrothermograph (Figure 7) was used to record the air temperature at a height of 1 m within each stand. The accuracy of these instruments was ±1.0°C. They were mounted in small Stevenson screens and their calibration was checked weekly against a mercury thermometer. Temperatures were read from the charts at two hourly intervals because the graduations on the chart were small and it was impractical to deal with shorter time periods. Mean daytime temperatures were calculated from the readings obtained between sunrise and sunset.

At Site A, the hygrothermograph was in operation from June 4th to September 30th, 1970 and from May 8th to September 14th, 1971. At Site B, temperatures were recorded from June 25th to September 30th, 1970 and from May 1st to September 14th, 1971.

Figure 7 Hygrothermograph

The mean daytime temperatures are presented graphically. The daytime average for each month was calculated and the differences between Site A and B tested for significance using the paired t-test. Comparisons were also made with air temperatures recorded from a shielded thermistor probe above the vegetation (3 m).

(b) Temperature Profiles

Temperature profiles were studied at Site A in 1970 (July 1st to September 30th) and at Site B in 1971 (July 17-29th and August 17-26th). A recorder was not available for Site B in 1970, and in 1971 the instrument at Site A was plagued with frequent breakdown. The data obtained at Site B in 1971 was intermittent, July 17-29 and August 17-26 because of a factory defect in the recorder.

Six thermistor probes at -25 cm, -10 cm, 0 cm, 1 m, 2 m and 3 m heights relative to the soil surface were used at Site A. The thermistors, meter, amplifier and switchbox were supplied by Atkins Technical Inc.; the recorder was an Esterline Angus galvanometer type with a span of 0 to 1 ma.

The six temperatures in the profile were recorded every six minutes but only hourly data were used, thus reducing the volume of data and the analysis and computation times. When analysing the data from the charts, readings were estimated to the nearest 0.1 ma. A sub-routine in the Fortran program for temperature analysis (Appendix B) performed the conversion from milliamperes to degrees centigrade using the constants computed from a weekly calibration.

At Site B in 1971, a Grant Model D temperature recorder was used to monitor the temperature profile. The accuracy of this instrument was ±0.2°C and the chart was read to the nearest 0.5°C. Shielded thermistor probes were positioned at heights of 1 m, 2 m and 3 m in the stand and soil probes were located at the soil surface, and at -5 cm, -10 cm and -25 cm.

The temperature data was keypunched and all computations were carried out by an IBM 360 model 65-IH computer.[1] The program has a capacity for 16 days of data with options for 15 minutes, 1 hour and 2 hour recording intervals. Average temperatures for each 24 hour period and each daytime and nighttime interval were calculated as well as average daily, daytime and nighttime temperatures for each 16-day data set.

Average daytime temperatures at each level in the profile were calculated for July, August and September in 1970, and for July 17-29 and August 17-26 in 1971. These were plotted to show the average shape of the temperature profiles.

Average daytime air temperatures at the various heights were compared statistically with the paired t-test and the temperature recorded by the thermograph was also compared (paired t-test) with that at 3 m.

(c) Lysimeter and stand soil temperatures

Soil temperatures within the lysimeters and in the undisturbed soil of the stand were obtained to compare their thermal regimes. This facet of the research was done in the summer of 1972

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[1] The program was written in WATFIV by Mr. Donald Newsham. See Appendix A.

because recording equipment was not available during the main study. The Grant thermistor equipment was used to monitor the temperatures at the soil surface, -18 cm and -37 cm, in the center and at the periphery of the soil monolith of lysimeter 1B. Stand soil temperatures were monitored at a distance of 1 m from the lysimeter.

Average daily temperatures (00 hr to 2400 hr) for each level in the lysimeters were calculated and compared with the average daily temperature at the same level in the stand (t-test). Differences in average daily temperatures in the center of the lysimeter and at the periphery were also tested for significance.

4. Wind Speed

Wind speeds above the stands were monitored using sensitive 3-cup anemometers with starting speeds less than 0.09 m sec^{-1}. A Casella anemometer (Figure 8) was used at Site A in 1970 and 1971 and at Site B in 1971 while a Thornthwaite anemometer of similar design was used at Site B in 1970. They were of the "light chopper" type, a totalizing digital counter recording the number of revolutions made by the cups. The accuracy of the both instruments was ±0.03 m sec^{-1} over a 10 min time interval. In 1970, the anemometer at Site A was initially mounted at a height of 1.75 m on June 26th, moved to 2 m on July 10th and to 2.25 m on July 27th. The mounting height was increased to keep the cups above the vegetation. The anemometer for Site B was not available until July 20th and was mounted at 2.25 m because the plants had achieved maximum height by that date. In 1971, they were mounted at 2.25 m for the entire season.

Figure 8 Casella anemometer

Two readings were made on each visit to the sites -- one on arrival, the other on departure. Using the elapsed time in minutes and the difference between the counter readings, counts per minute were computed. Tables provided by the manufacturer were used for the conversion to meters per second. The average daytime wind speed was calculated from early morning and late evening readings. The daytime wind speed for the two sites is presented on the same graph. Mean daytime wind speed was computed for each site and the differences tested for significance using the paired t-test.

5. Relative Humidity

The relative humidity of the air at each site was recorded by the hygrothermographs mentioned in Section 3 (p. 33). The accuracy of these instruments is ±5 percent. The calibration was checked weekly against relative humidity readings measured with a sling psychrometer. Relative humidity readings were taken from the charts every two hours and the average daytime relative humidity calculated from data between sunrise and sunset. The average daytime relative humidity is presented graphically. Mean daytime values for each month were also calculated and differences between the daytime average at each site were tested for statistical significance.

6. Precipitation

The precipitation between May 1st and September 30th in 1970 and 1971 was obtained from the Delta (University) meteorological station report. A Canadian standard rain gauge was used, being mounted at a height of 30.48 cm (12 in) above a clipped grass surface near Mallard Lodge (Figure 2). It formed part of the Meteorological Station installed by the Department of Transport (Canada) in 1969. The rainfall for each 24 hour period was recorded at 0900 hr.

B. Soil Analysis

1. Sampling

Soil cores were obtained from each site on September 1, 1971, to study the texture, structure, moisture and organic content. The sampling points were selected by tossing a weighted marker over the investigators shoulder. Three cores (5.08 cm x 100 cm) were sampled at each of four points at Site A and five at Site B, and were extracted in 20 cm units. Each sample was stored in an airtight plastic bag at 4°C until analyzed. There was no sign of mold or decomposition at the time of analysis.

2. Structure

The structure of the aggregates in each zone was examined when the cores were sampled and additional structural information was obtained when the samples were analysed.

3. Particle Size Analysis

The particle size was studied to arrive at an estimate of the specific yield of the soil. The specific yield is dependent on the pore space which in turn is a function of the particle size. The pipette method was used to determine soil size fractions [Kilmer and Alexander, 1949]. Approximately 10 gm of each soil sample was placed in a 250 ml beaker and weighed to the nearest milligram. Distilled water was added to make a thin paste and 5 ml of 30 percent H_2O_2 added to digest the organic matter. Heat was applied to speed up the reaction and additional amounts of H_2O_2 added until no further reaction occurred. Ten millileters of dispersing solution (35.7 gm Calgon ℓ^{-1}) was added followed by distilled water to make a total volume of 200 ml. It was then placed on a mechanical stirrer for ten minutes. After settling for a few minutes the suspension was poured through a 250 mesh seive into a 1000 ml graduated cylinder. The remaining sediment was rewashed with distilled water until all the fine particles which formed a temporary suspension were removed. The particle fraction which failed to pass through the seive ≥ 62 microns (μ) in diameter, was returned to the beaker, dried at 105°C for 24 hours and reweighed.

The suspension in the graduated cylinder was made up to 1 ℓ with distilled water and mixed thoroughly with a plunger to resuspend the particles. The time, t_0, was recorded and a 25 ml sample was immediately withdrawn with a pipette from 10 cm below the liquid surface. This aliquot was placed in a tared 50 ml beaker and dried at 105°C. After drying, the beaker was cooled in a desiccator and reweighed. Because the volume sampled (25 ml) is 1/40 of the total volume of the suspension, the dry weight of the soil particles in this aliquot represents 1/40 of the total weight of particles $< 62\,\mu$ in the initial sample.

The suspension was allowed to settle for seven hours and four minutes,[1] at 25°C when all the particles larger than $2.0\,\mu$ had settled below the 10 cm depth. Another 25 ml sample was pipetted from the 10 cm depth and dried at 105°C. The weight of this fraction represents 1/40 of the total weight of particles $< 2\,\mu$ diameter in the original sample.

Calculations:

Weight of particles $\geq 62\,\mu$ = (2)

Weight of particles $< 62\,\mu$ in 25 ml = (3)

Weight of particles 2μ in 25 ml = (4)

Weight of Calgon in 25 ml =
$(0.01 \times 35.7)\ 0.25 = 0.0089$ gm (5)

Total weight of particles
$2\mu \leq X < 62\,\mu = ((3) - (4)) \times 40$ (6)

Total weight of particles
2μ in sample $= ((4) - (5)) \times 40$ (7)

Total weight of soil recovered
$(2) + (6) + (7)$ (8)

% particles $\geq 62\,\mu = (2)/(8) \times 100$ (9)

% particles $2\mu \leq X < 62\,\mu = (6)/(8) \times 100$ (10)

% particles $<2\mu = (7)/(8) \times 100$ (11)

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[1] Sedimentation times were calculated from "Stokes law," assuming the average density of soil particles to be 2.61 gm cc^{-1}.

The results from the particle size analysis at each level were pooled and the average percentages of each size fraction presented in a cumulative percentage bar graph. The United States Department of Agriculture (USDA) soil classification was applied to the results from each level. This classification was used so the specific yield of the zones could be estimated from Meyboom's table [Meyboom, 1967, p. 22] which also used this system.

4. Moisture Content

Each sample was placed in a tared 600 ml beaker and weighed, then dried at 105°C for 24 hours. The dry weight and loss of weight on drying was determined and using these values, the moisture content was calculated by the formula:

$$\text{\% water by wt.} = \frac{(\text{wet wt.} - \text{oven-dry wt.})}{(\text{oven-dry wt.} - \text{tare wt.}} \times 100$$

The average moisture content was calculated for each 20 cm unit by summing the data for each level and dividing by the number of samples from each site. The results will be presented in tabular form.

After weighing, the dried soil was ground in a mortar and pestle; caution was exercised to insure that large particles (gravel or sand) were not pulverized. The three samples from the same depth and location were pooled and three subsamples withdrawn, one for organic determination and the other two for particle size analysis.

5. Organic Content

The analysis of organic matter was done by the soil testing laboratory, Department of Soil Science, University of Manitoba. Organic carbon content was determined from the amount of potassium dichromate reduced by a small amount of each sample. [Peech *et al.*, 1947] A 0.5 gm sample of soil was placed in a beaker and 10 ml $K_2Cr_2O_7$(1N) and 20 ml concentrated H_2SO_4 added. It was allowed to stand for one hour, diluted to 200 ml with distilled water and titrated with ferrous sulphate (0.5 N) to a turquoise end point. The formulas used to compute organic matter are as follows:

$$K_2Cr_2O_7 \text{ reduced (ml)} = \frac{\text{blank} - (\text{ml of } FeSO_4 \text{ titrated} \times 10)}{\text{blank}}$$

where

blank = ml of $FeSO_4$ in titration of 10 ml of $K_2Cr_2O_7$

$$\text{Percent organic matter} = \frac{\text{ml of } K_2Cr_2O_7 \text{ reduced} \times 0.67}{\text{sample weight}} .$$

Two cores were analysed for each site and means and standard deviations computed for each 20 cm zone.

C. Measurement of Water Table Fluctuations

Water table levels were recorded on float operated water level recorders (Stevens Type F) (Figure 9) mounted on 15.2 cm (6 inch) diameter observation wells. Weekly charts were used with a

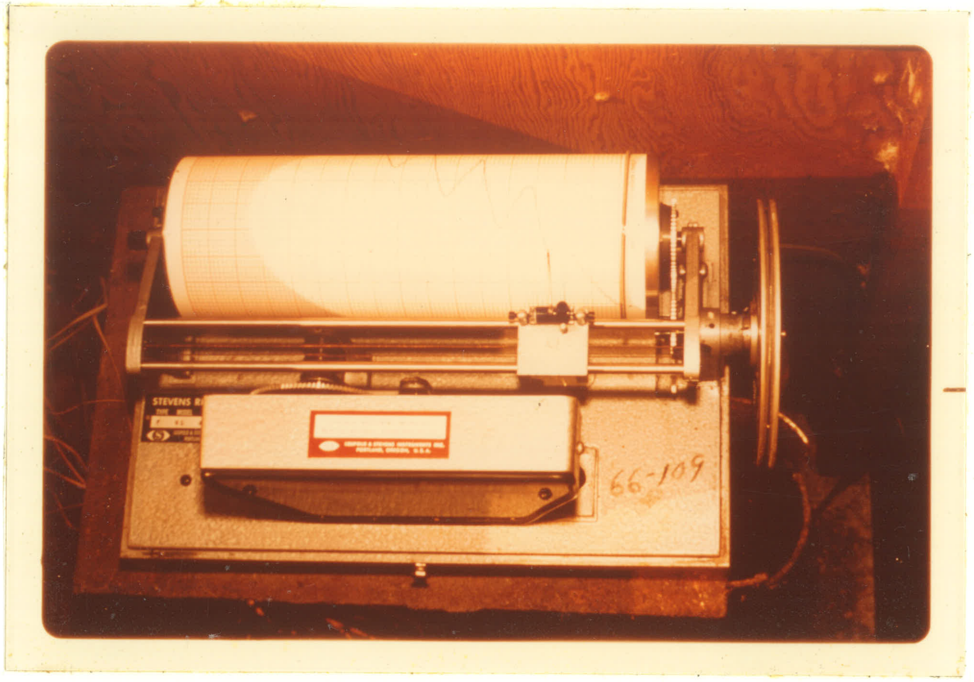

Figure 9   A Stevens water level recorder

float to chart ratio of 1:1. Well A4 was installed by the Hydrologic Sciences Division of the Inland Waters Branch, Department of Energy, Mines and Resources, for the Portage diversion groundwater investigation. It was 6.1 m (20 ft) deep and 9 meters NW of the *Phragmites* stand at Site A (Figure 3). In 1971 I installed a second well, A5, 3.05 m (10 ft) deep within the *Phragmites* stand to compare the water table response within the stand and beyond the periphery. The casing was a 15.2 cm (6 in) diameter galvanized heating duct slotted profusely to allow maximum seepage. A similar well, B4, was installed at Site B in 1970 (Figure 4). The shallow ground water table fluctuations (and levels) were recorded at Site A from June 28 to September 30, 1970 and from May 23 to September 13, 1971. At Site B water table data were obtained from July 16 to September 30, 1970 and from May 22 to September 13, 1971. Analysis of the water level records followed the method of White [1932] who derived the formula:

$$E_{WT} = (24\, r + s)\, y$$

where

E_{WT} = consumptive use of water by evapotranspiration

r = rate of recharge of the water table equivalent to the average rate from 00 hr to 0400 hr

s = net drop in the water table per day

y = readily available specific yield of the soil, defined by Meyboom [1967] to be the ratio of the volume of water that a saturated soil will yield by gravity in 24 hours to the volume of the soil.

All parameters except specific yield, were obtained directly from the hydrograph as demonstrated in Figure 10. The amount of water contributed to the system by ground water recharge over each 24 hour period (24 r) was determined by connecting the 00 hr and 0400 hr points on the record and extending the line to intersect the following 00 hr. The net drop in the water table (s) over this same period was also measured directly from the chart as shown.

The readily available specific yield of the soil was estimated from soil particle size data for each site. Meyboom [1967, p. 22] relates specific yield values to soil classes based on percentages of sand, silt and clay. Using the results of the particle size analysis for Site A and Site B, the readily available specific yield was chosen at 9 percent and this figure was used in all the analyses. The daily estimate of the amount of water removed from the saturated zone in the soil calculated by this method was presented graphically. The position of the water table in relation to the soil surface (0 cm) was also presented on the same figures.

D. Measurement of Evapotranspiration

1. Lysimeter Design

Small hydrostatic lysimeters (Figure 11) were used to measure the evapotranspiration rate of *Phragmites communis* at the two sites. The lysimeter design was based on that described by Hanks and Shawcroft [1965].

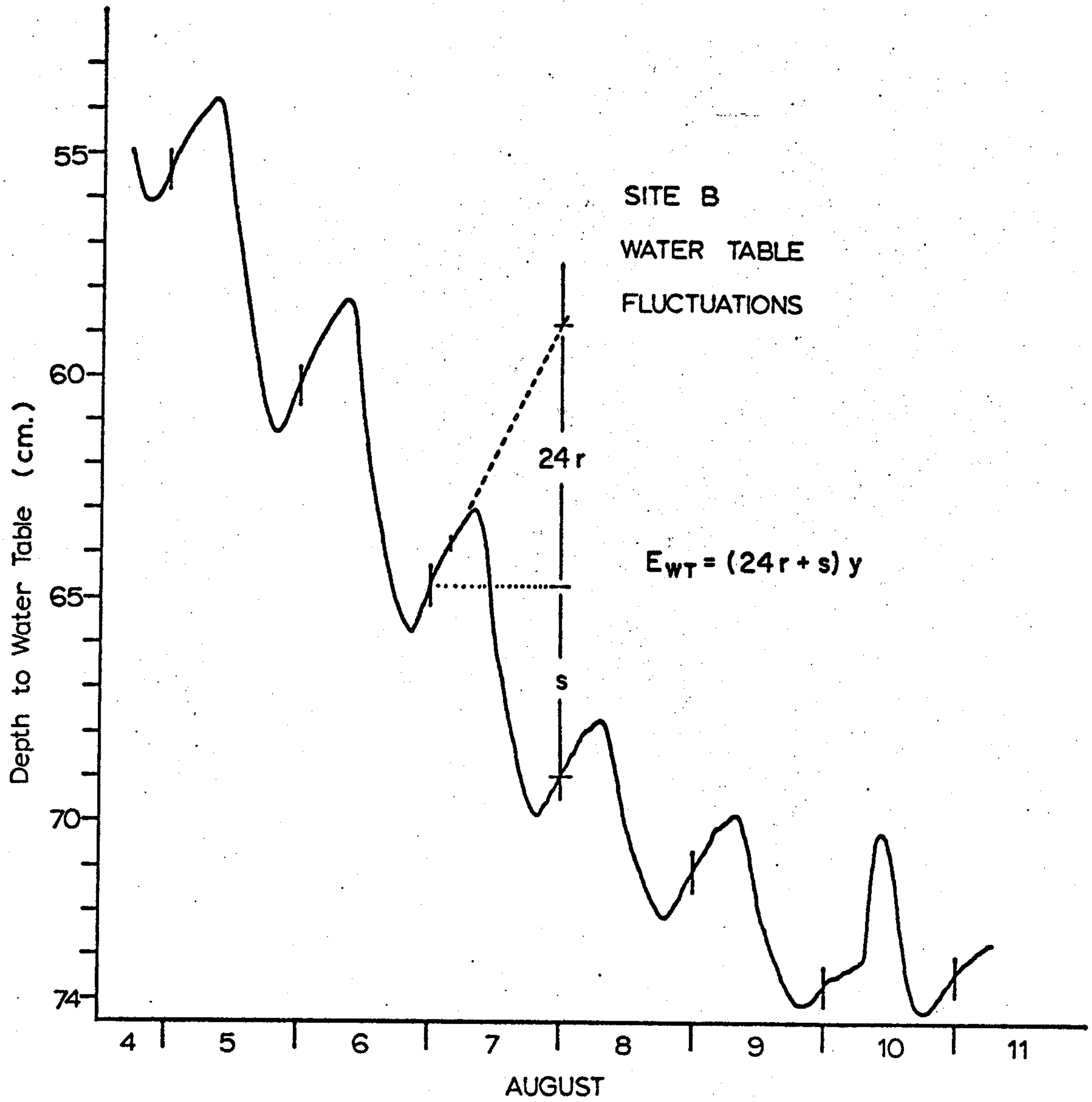

Figure 10 Copy of a water table hydrograph showing diurnal fluctuations in the water table and the graphical solution of White's formula

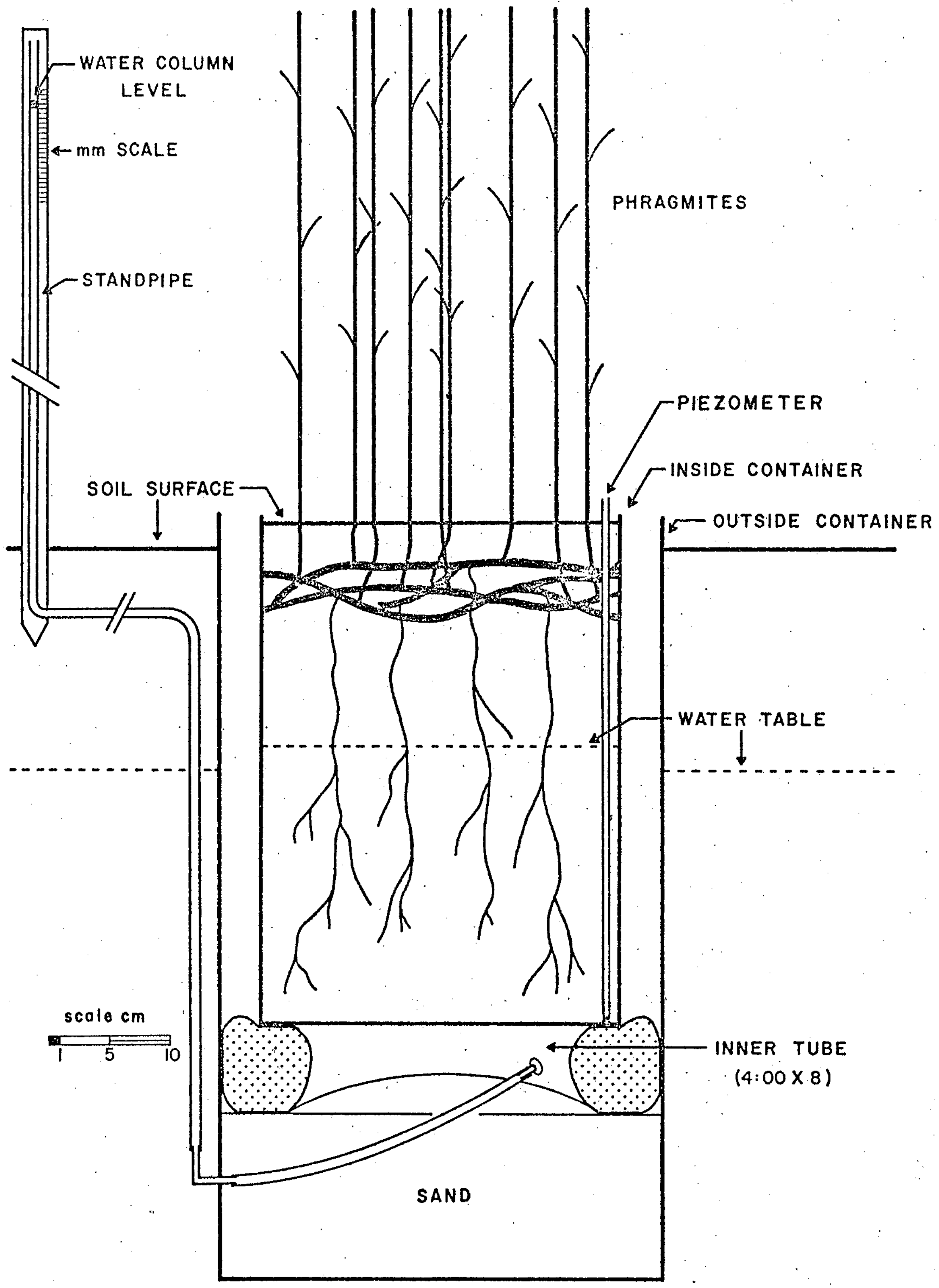

Figure 11 Line drawing of the lysimeters used in 1970

The functional components of these lysimeters were: (i) the inside container holding the soil-plant unit; (ii) an inner tube (bolster) filled with water and connected to a stand pipe (to support the weight of the lysimeter); (iii) a millimeter scale to read the height of the water column in the standpipe; (iv) an outside container to support and isolate the bolster and inside container.

When assembled, the weight of the inside container creates a pressure within the inner tube which forces water via the hose assumbly into the standpipe. The pressure in the inner tube is balanced by an equal but opposite pressure (p) in the standpipe which is a function of the height (h) of the water column and the density (d) of the liquid (p = hxd). The weight of the inside container is lessened when water is lost by evapotranspiration, resulting in decreased pressure in the inner tube and a reduction in the height of the water column.

The outside container was a metal drum, 64 cm high and 35 cm in diameter. Sufficient sand was placed in the bottom to prevent it from floating out of position. The sand also served as a spacer, to raise the inside container so that its rim was flush with the soil surface. A disc of plywood was laid on the upper surface of the sand to provide a solid platform for the bolster and inside container. An inner tube, size 4:00 x 8 was used as the hydrostatic bolster. It was completely filled with water and connected to the stand pipe as shown in Figure 11.

Five locations were selected within each *Phragmites* stand for lysimeter installations. The prerequisites for the selection were that the area have uniform distribution of plants with average or above average densities. The installations were placed far enough apart so they were completely isolated from neighboring lysimeters. A pit the same dimensions as the outside container was dug at each location and the outside container placed in it. Every attempt was made to insure that the lysimeters were indistinguishable from their surroundings. There was no disturbance to the south, east or west and only a narrow foot path to the north of each installation.

The stand pipe was supported by a wooden stake, driven in the ground 0.6 m north of the lysimeter and adjacent to the access path. To reduce the effect of temperature on the stand pipe system, the length of hose between the standpipe and the lysimeter was buried about 15 cm below the soil surface.

The standpipe water columns for all the lysimeters were adjusted to the same height relative to the container rims by varying the volume of water in the bolster-standpipe system while being activated by a weighted container. To prevent evaporation from the system, and to improve the resolution of the readings 2 ml of automobile transmission oil (red) was floated on the water column in each standpipe.

The inside container of each lysimeter was a 22.7 ℓ (5 gallon can) metal container 39 cm deep and 28.5 cm in diameter, with the top removed. Soil-plant units (monoliths) of these dimensions were removed intact from an adjacent stand of similar density and composition. Another can with the bottom removed was used to support the monolith while it was being transferred to the permanent container. Soil was removed on the outside with a posthole digger and when the required depth was reached, a plywood platform, sharpened on one edge was inserted beneath the monolith and it was lifted out in an upright position. The plywood was replaced with a sheet of 2 mil (0.025 mm) polyethylene which was used as a sling to lift the unit into the mouth of the 5 gallon can. The monolith was then allowed to slide from the supporting metal cylinder into the permanent can.

Soil was packed around the edges to fill any air spaces between the container and the monolith. A small piezometer was installed in each soil unit and packed in place with fine gravel. Piezometers, which are similar to small diameter observation wells, are used to measure the hydraulic head of ground water aquifers and were used in this case to measure the level of the water table in the lysimeters. These piezometers were made from 0.95 cm (3/8 in) inside diameter PVC pipe, 43 cm long. The lower end was closed with a stopper and the entire length was slotted with a hacksaw at 1.27 cm (1/2 in) intervals. A wire "dipstick" was used to measure the water level in the piezometers.

2. Lysimeter Modifications, 1971

In 1971, two modifications were made in the lysimeters (Figure 12). One of these was the incorporation of a drainage chamber under the soil unit.

In these lysimeters, the addition of water from the marsh with its high content of total dissolved solids [1580 ppm, Gilliland, 1965], would have resulted in the accumulation of high concentrations of salts and minerals in the soil. In 1970, rainwater was added to

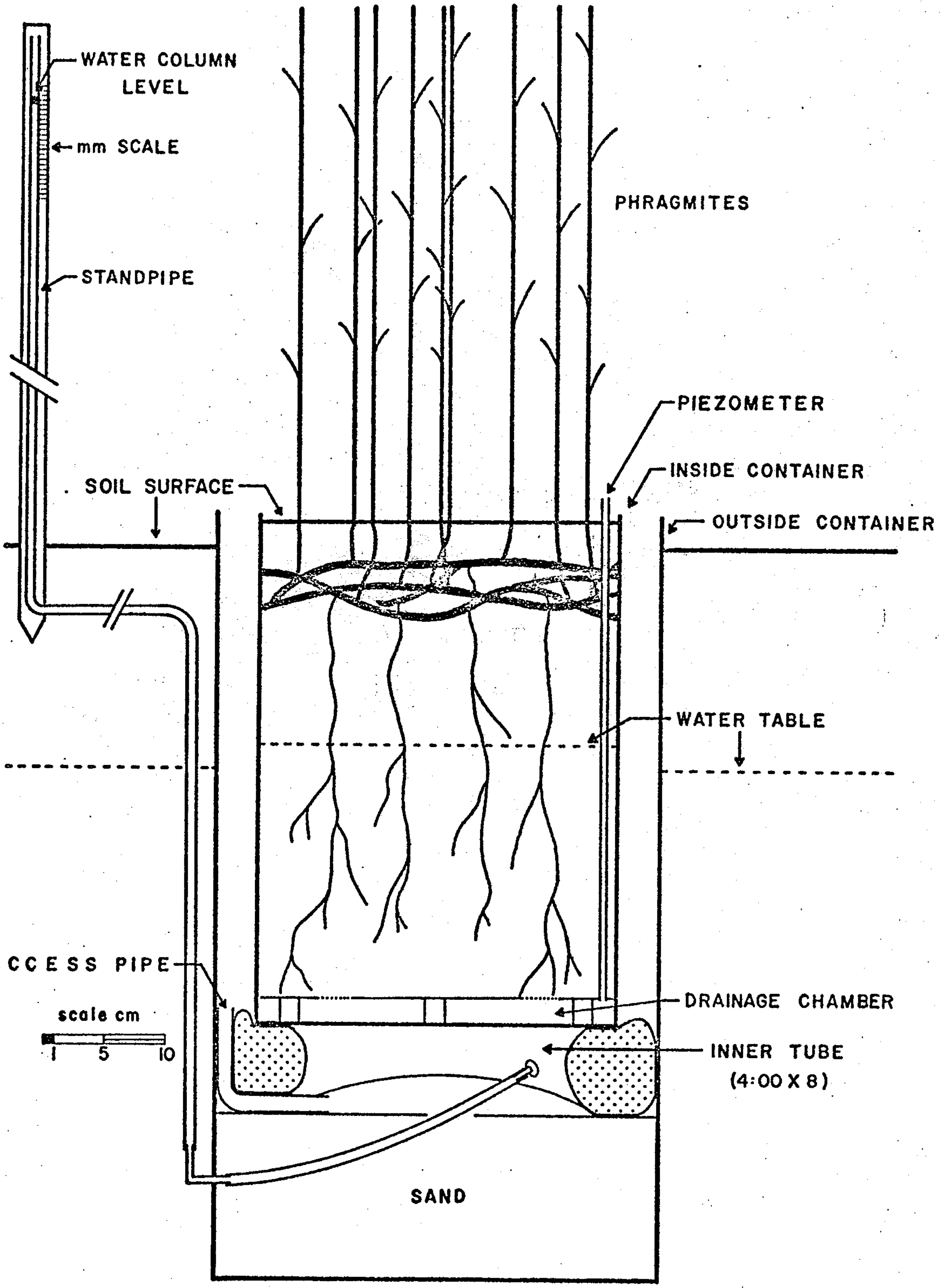

Figure 12 Line drawing of the lysimeters used in 1971

prevent this from occurring, but it was felt that the continuation of this practice in 1971 might have depleted the nutrient levels in the lysimeters. The incorporation of the drainage chambers in 1971 enabled the author to add ground water with a natural supply of nutrients but the accumulation of minerals could be prevented by pumping the water out each week and replacing it with fresh ground water. The volume of water removed was measured and the same volume replaced, water for replacement being from a shallow ground water well at the site. Replacing the water via the drainage chamber access pipe ensured that the normal moisture distribution in the soil surface was not altered.

The drainage chambers were formed by constructing a support which held the soil unit about 1.9 cm (3/4 in) above the bottom of the container. The supports consisted of metal discs, 27 cm in diameter with four 5 cm diameter holes covered with wire mesh and resting on five 1.9 cm (3/4 in) legs. A vertical access pipe 9.5 cm (3/8 in) inside diameter was used for changing the water, adjusting the water levels to match those in the stand and measuring the water table levels in place of the piezometer used in 1970.

The second modification was an access pipe to remove water from beneath the inside container after the space between the two containers had been flooded by rainfall. In 1970, the problem of flooding was not encountered until late in the season (September) because the layer of dry sand in the bottom of the outside container absorbed the rain water which entered. However, once the sand was saturated ,water from heavy rains filled the space around the bolster under the inside container. Since the original design did not provide a means of removing this water, the inside container had to be lifted out. In 1971, an L-shaped copper pipe, 1.27 cm (1/2 in) in diameter was installed with the vertical arm between the outside container and the inner tube and with the horizontal arm beneath the inner tube and extending into the central space. Rain water was easily removed via this pipe with a bilge pump fitted with a small flexible hose.

The level of the water table in the stand was duplicated in the lysimeters except at Site B in the late summer, when the water table was lower than the maximum depth of the lysimeter. In this case, a water table 5 cm above the bottom of the lysimeter was retained. It is felt that this did not create unnatural soil moisture conditions in the lysimeters, because the moisture content of the 21-40 cm zone was not lower than the 81-100 cm zone when the water table was at -89 cm (Table XV, Site B, p. 128). Furthermore, the larger roots of *Phragmites* penetrate to a depth of 60 cm at Site B and finer roots probably go deeper and therefore the roots of plants in the stand are in contact with the saturated zone throughout the season. In order to duplicate this situation without increasing the depth of the lysimeter, it was necessary to retain the water table in them.

Three "green" lysimeters, with *Phragmites* growing in them were used to measure evapotranspiration at each site (Figure 13). A fourth lysimeter, hereafter referred to as the *evaporation lysimeter*, had no living plants in it, but the litter on the soil surface and the dead stems from previous years were left intact. It was used to

Figure 13   Evapotranspiration lysimeter with live *Phragmites*

measure the evaporation rate from the soil surface.

To compensate for temperature induced fluctuations in the standpipe[1], a control lysimeter (Figure 14) was installed at each site. The inside container (a 5-gallon can with a welded top) was filled with sand and water until its weight was approximately equal to that of the monoliths.

The readings from the control lysimeter at each site were applied as a correction factor to the readings from the other four lysimeters. Immeasureable factors such as changes with time of the elastic properties of the inner tube and changes in volume as a result of stretching were also accounted for by this lysimeter.

3. Lysimeter Readings

Lysimeter readings involved recording the level of the water column (top meniscus of the oil layer) in relation to the millimeter scale of the ruler (Figure 15). When reading the water column levels in the standpipes, it was important that the line of sight be perpendicular to the standpipe each time. Precision in this regard was developed with practice and all the readings in 1970 were made without the aid of a leveling device. In 1971, an assistant made some of the observations, and a sighting device[2] with a bubble level and a

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[1] The temperature of the water in the standpipe of the lysimeters varied with the diurnal rhythm of air temperatures. An increase in the ambient temperature from 10°C to 30°C causes the density of the water to decrease from .99973 q cm^{-3} to .99567 q cm^{-3} [Smithsonian Tables, [Hodgman, 1960, p. 2142]. To exert the same pressure at higher temperatures, the water rises in the standpipe.

[2] True Sight Hand Level by David White and purchased from Forestry Suppliers Incorporated.

Figure 14 Control lysimeter

Figure 15 View of the standpipe, ruler scale, oil layer and reading position (pen)

horizontal cross hair was used. This insured that the line of sight was level with the upper meniscus of the oil layer, and obviated observer discrepancies.

The stand pipe levels were read at two hour intervals on most days. Readings began at between 0800 hr and 0900 hr Daylight Standard Time (DST). Earlier readings were not possible because dew accumulation on the leaves resulted in negative values for the night and high evapotranspiration rates between sunrise and the time by which the dew had evaporated. Occasionally dew was still present on the leaves at 0900 hr. Final readings were made at sunset or shortly after. The order in which the sites were visited varied from day to day and because of the distance between the sites, the reading times differed by about 30 minutes. The lysimeters were initially installed in June and July of 1970. Because of the frozen ground no digging could be done until the end of May, therefore lysimeter installations were not completed until July 28th. Although the "green" lysimeters were in operation after July 4th, the evaporation lysimeters were not completed until July 28th. The intervening time was absorbed in solving minor problems in methodology, standardization and calibration of the lysimeters.

A total of 28 days of data was collected from July 28 to September 30, 1970. In 1971, the lysimeters were in operation from June 1 to September 10 and a total of 42 days of data were obtained. The timetable of readings was designed to obtain 4 days of data per week but the data collected on rainy days could not be used because the interception loss was not known. Equipment maintenance and unscheduled commitments also resulted in incomplete data for some of the days. Only data for complete days, that is, early morning to sunset, or sunset to sunset, were used in the calculations.

Readings were continued through the night on July 7, 1970, and August 31, 1970, but no further night observations were recorded after it was found that the water use was so small that it could not be detected by these lysimeters.

4. Evapotranspiration Calculations

The following sequence was used to calculate evaporation, transpiration and evapotranspiration from the standpipe readings: The daily change in the height of the water columns was found by subtraction of the last reading in the evening (sunset) from the last reading the evening of the previous day (or the first reading in the morning if it occurred before 0900 hr). The change in height of the control lysimeter was applied as a correction factor to the height changes of the evaporation lysimeter and the three "green" lysimeters. The corrected height changes were multiplied by the lysimeter constant (ml cm^{-1}) to calculate the volume of water lost from each lysimeter. The volume of water transpired by the plants in the "green" lysimeters was obtained by subtracting the loss by the evaporation lysimeters (ml day^{-1}) from the total loss (ml day^{-1}). The total transpiration (ml day^{-1}) was determined to average out differences between lysimeters. The transpiration rate per unit leaf area (ml dm^{-2} day^{-1}) was then determined by dividing the transpiration (ml day^{-1}) by the combined leaf areas (dm^2) of the lysimeters. To calculate the transpiration by the stand, the leaf area (dm^2 leaf m^{-2} ground area) was calculated and multiplied by the transpiration rate (ml dm^{-2} day^{-1}).

This transpiration value, (ml m^{-2} ground area day^{-1}) was then converted to mm H_2O day^{-1}. Evaporation (ml lysimeter $area^{-1}$ day^{-1}) was also converted to (mm H_2O day^{-1}) and the evaporation and transpiration figures added to arrive at a figure for evapotranspiration (mm H_2O day^{-1}) from the stand. Evapotranspiration is presented in mm H_2O day^{-1} because the units of area are dimensionless and the values can be converted easily to volume per unit area for a region of any size.

E. Measurement of *Phragmites* Shoot and Stand Characteristics

1. Leaf Area and Plant Height

Because the transpiration rate of the plants is primarily dependent on the area of the transpiring surface [Tanner and Lemon, 1962], a careful analysis of leaf areas was conducted. Comparative leaf area and density determinations were also required for the stand and lysimeters so evapotranspiration rates could be converted to stand values. A similar conversion based on leaf areas and shoot density was used by Gel'bukh [1964] because he found, as did the present author, that the amount of vegetation in the lysimeters differed from that in the stand. Finally, leaf area and plant height were used as indices to compare the growth of the plants in the lysimeters with those in the stand.

In 1970 the total leaf area of the plants in the lysimeters and 40 "stand plants" at Site A and 58 stand plants at Site B were determined. The term "stand plants" is defined as those growing naturally within the *Phragmites* community. The plants were chosen by throwing a weighted marker into the stand and labelling the shoots growing in a circular plot, 28.5 cm in diameter (638 cm^2), on the east side of the marker. This plot diameter was chosen to correspond with the size of the lysimeters.

The weighted marker consisted of a two meter length of cord, one end attached to a lead weight and the other to a piece of heavy paper painted flame orange. The weight fell through the vegetation to mark the point while the card was caught in the tops of the *Phragmites*. This method was chosen because sampling from a square grid would have caused serious damage to the stand.

In 1970, the plants were marked in four 638 cm^2 plots at Site A and in five at Site B. Measurement dates for 1970 are listed below:

Site A - Lysimeters

July 11, 25, August 11, 27, September 12, 24 and 30.

- Stand
August 21, September 12, 24 and 30.

Site B - Lysimeters

July 9, 25, August 11, 27, September 12, 23 and 30.

- Stand
July 30, August 27, September 12, 23 and 30.

In 1971, leaf area measurements were made on all plants growing in the lysimeters plus 40 plants in each stand. Measurements were time consuming and 40 plants at each site plus the lysimeter plants were all that could be measured on a weekly basis. The number of sample points in each stand was increased to eight and the first 5 plants in a straight line running in a westerly direction from the marker were chosen. The sampling program was changed in 1971 because small clones within the stands were found to have an unrepresentatively high shoot density, shorter stems and lower leaf area. The 1971 sampling program extended the distribution over a larger area in the stand, thus avoiding large numbers of these unrepresentative plants. The leaves were measured twice a week in June and once a week from June 29 to September 7.

The length and maximum width of each leaf was measured and leaf area was calculated by the equation:

$$\text{Area} = \frac{\text{length x width}}{1.67}$$ [Walker-Shay, personal communication)

The factor of 1.67 was checked to ensure that it applied to the present study. Ten *Phragmites* plants were chosen from each site and replicas of the leaves were obtained by exposing them on a sheet of high quality light sensitive paper. The paper silhouettes were cut out and weighed and the area was calculated using the weight to area ratio of the paper. The factor for each leaf was found by dividing the product of the length and width by the area of the outline. The mean value for the factor deviated only slightly from that determined by Walker and because her value (1.67 ± 0.16) was based on a larger sample, it has been used in the present study.

The plant heights were measured at the same time as the leaves in both seasons. Measurements were made to the point of attachment of the most recent fully expanded leaf. The average leaf area per plant and height per plant were calculated from measurements made after the plants had reached maturity. The average for the stand was compared statistically with the average for each lysimeter (t-test for the difference between means).

The total leaf area for each lysimeter, plus the leaf area of a comparable area in the stand was used to compare transpiring surfaces through the season. The leaf area of the stand was found by multiplying the density of shoots per 0.0638 m^2 plot by the average leaf area per plant. The leaf area index (leaf area per unit ground area) was also determined for the stands at Site A and Site B in 1971 to compare rates of leaf development and senescence.

2. Plant Density

In 1970 the density of *Phragmites* plus the understory species was determined by counting the plants in a number of circular plots (0.0638 m^2). A wire ring made by interlocking two semi-circles was used to outline the plots because of the ease with which the semicircles could be placed around the plants. Thirty plots were examined at each site, sampling points being chosen at three-pace intervals along two transect lines parallel to the long axis of each stand and 20 m apart.

In 1971, the quadrat size was increased to 0.25 m^2 and 40 quadrats were sampled. The changes in quadrat and sample size from those in 1970 were made to reduce the standard deviation of the sample mean. Ten 1 m^2 quadrats were located with a weighted marker and each was subsequently divided into 4 quadrats of 50 cm to the side. The weighted marker was thrown from predetermined locations on the access trails and in predetermined directions to obtain a good coverage of each stand. The density of the *Phragmites* plus the understory species was used to compare the composition of the two stands and the density of the *Phragmites* to calculate the leaf area of the stand (density times leaf area per plant).

CHAPTER III

RESULTS

CHAPTER III

RESULTS

A. Environmental Parameters

1. Incoming Short-Wave Radiation

The total daily incoming short-wave radiation (R_I) obtained from the pyrheliograph record in 1970 is shown in Figure 16a. R_I ranged from 12 to 14 mm H_2O equivalent on sunny days in June and July, while on cloudy days, it was less than 3 mm H_2O equivalent. The maximum insolation was recorded on July 19, and had an energy value of 794 gm cal cm^{-2} day^{-1} equivalent to the latent energy required to evaporate 13.6 mm of water. Peak R_I values of 12 to 14 mm H_2O were recorded on 7 days between June 21 and July 16. Incoming radiation levels peaked slightly higher in 1971 than in 1970 (Figure 16 b). June and July, had 12 days in which R_I was in the 12 to 14 mm H_2O day^{-1} range. The maximum for 1971 occurred on July 5 with 830 gm cal cm^{-2} day^{-1} or 14.2 mm H_2O equiv. day^{-1}.

The general trend of daily insolation for the marsh shows a gradual increase in June with maximum values occurring in the first part of July, followed by a decline until October.

The average daily R_I for each month of the 1970 and 1971 growing seasons (Tables I and II), were calculated from the data presented in Figures 16a and 16b. R_I was comparable for the month of

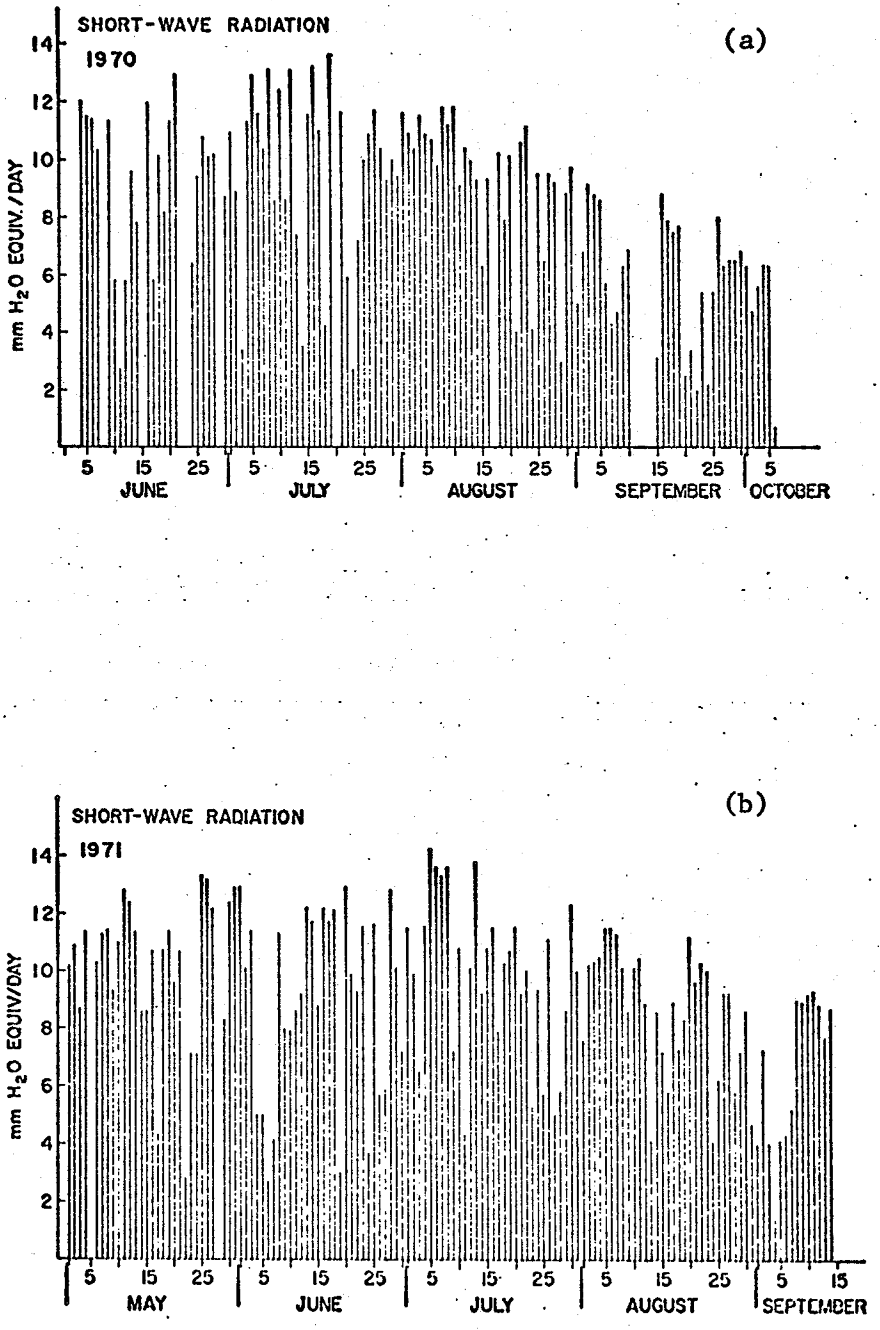


Figure 16 Daily incoming short-wave radiation (a) 1970, (b) 1971

TABLE I Average daily short-wave radiation on a monthly basis in 1970

	R_I gm cal cm^{-2} day^{-1}		R_I mm H_2O day^{-1}	
Month	mean	s.d.	mean	s.d.
June	541.44	151.6	9.27	2.6
July	565.29	179.54	9.68	3.09
August	552.07	123.21	9.44	2.12
September	352.36	123.39	6.01	2.11

TABLE II Average daily short-wave radiation on a monthly basis in 1971

	R_I gm cal cm^{-2} day^{-1}		R_I mm H_2O day^{-1}	
Month	mean	s.d.	mean	s.d.
May	598.87	146.76	10.17	2.5
June	522.88	187.83	8.95	3.23
July	573.65	160.88	9.81	2.76
August	505.19	125.45	8.65	2.16
September (1-14)	384.66	153.58	6.56	2.63

July in the two years, being 9.68 and 9.81 mm H_2O equiv. in 1970 and 1971, respectively, but there was a difference of 0.79 mm H_2O equiv. day^{-1} between the August 1970 and August 1971 means. The standard deviation of the mean was higher in July than in other months because of the greater range in the daily values, eg. 2.7 to 13.6 mm day^{-1} compared with 3.0 to 11.8 mm day^{-1} in August.

2. Net Radiation

The net radiation (R_N) measured over a *Phragmites* stand is only presented for the days that transpiration data is available (Figure 17). R_I for the same days is also presented to show the relationship between the two parameters. The range in the daily R_N was from 2.1 to 7.8 mm H_2O equiv. day^{-1}. The maximum of 7.8 was not recorded on the same day as the maximum R_I showing that measurements of short-wave radiation do not necessarily give a true indication of the net radiation. The equation relating these two parameters obtained by linear regression analysis is:

$$R_I = 0.61 - 1.61\, R_N : \quad r = 0.86; \quad s.b. = 0.18$$

The correlation coefficient is significant at $p < 0.01$. The scatter diagram and simple linear regression are presented in Figure 18.

The net radiation data were used to obtain correlations to show the dependence of evapotranspiration by *Phragmites* on the solar

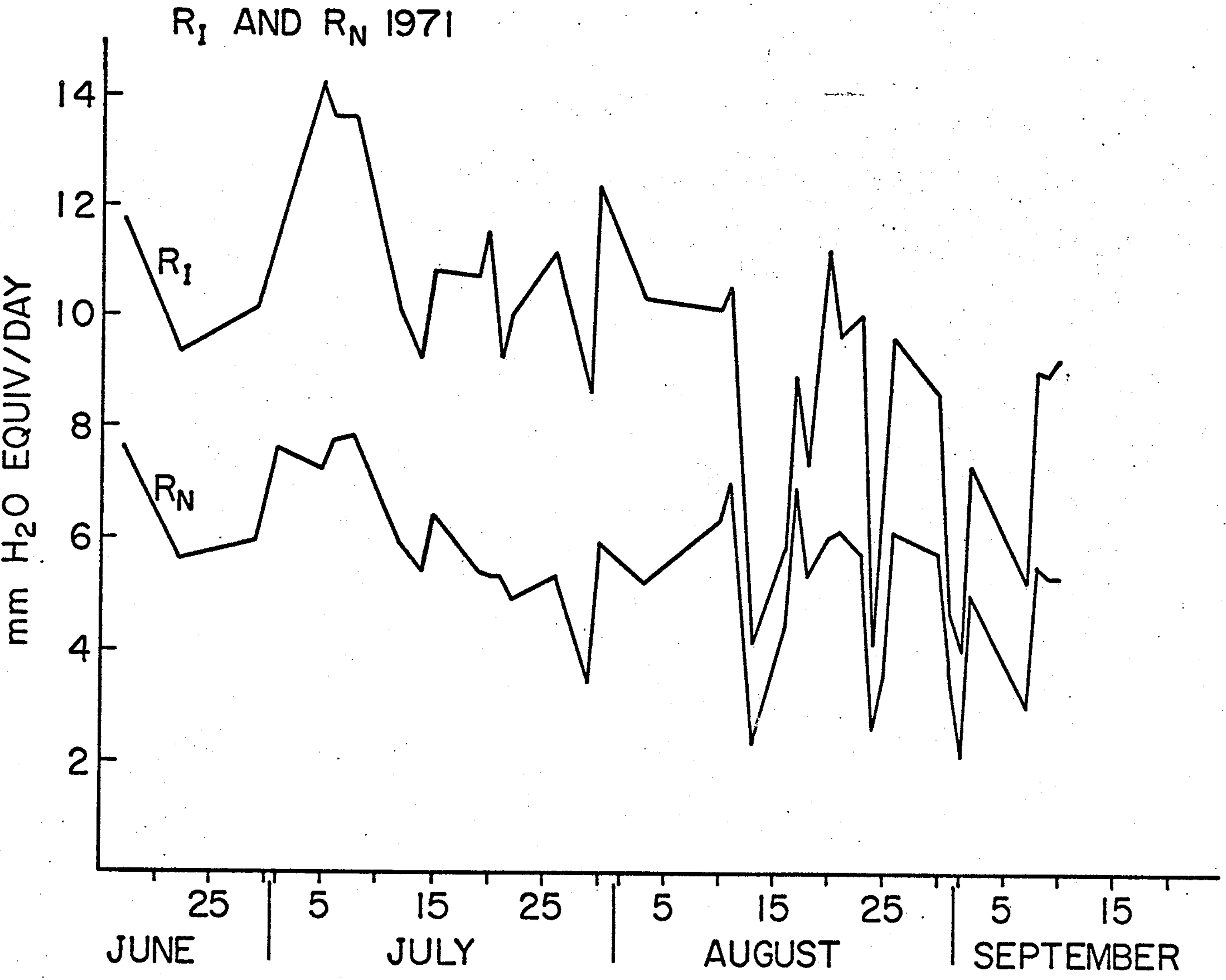


Figure 17 Short-wave (R_I) and net radiation (R_N) in 1971

energy available. The correlation analyses are presented in a later section.

3. Temperature

(a) Air temperature

In 1970, the highest mean daytime air temperature, (T_a) 28.4°C, was recorded on July 12 at Site A (Figure 19a). The air temperature at Site B (Figure 19b) was slightly lower; the highest daytime mean, 27.2°C occurred on August 13. The minimum air temperature for the season was recorded on September 13 being 5.5°C at Site A and 4.2°C for Site B. The seasonal pattern in T_a for the two sites was identical.

The average daytime air temperature in each month, June to September inclusive, is presented in Table III together with mean differences between the air temperature of the two sites and the t-statistic of the differences. The temperature differences between the two sites were small (<1.5°C) but statistically significant ($p < 0.001$).

The highest mean T_a in 1971 was 28.2°C at Site A on August 8 (Figure 19c) and 27.9°C at Site B on August 7 (Figure 19d). The lowest temperature recorded during the growing season was 8.5°C at Site A on May 17 and 5.4°C at Site B on May 1. Differences in the date of the lowest T_a occurred because the instrument at Site B was installed on May 1 and that at Site A on May 7.

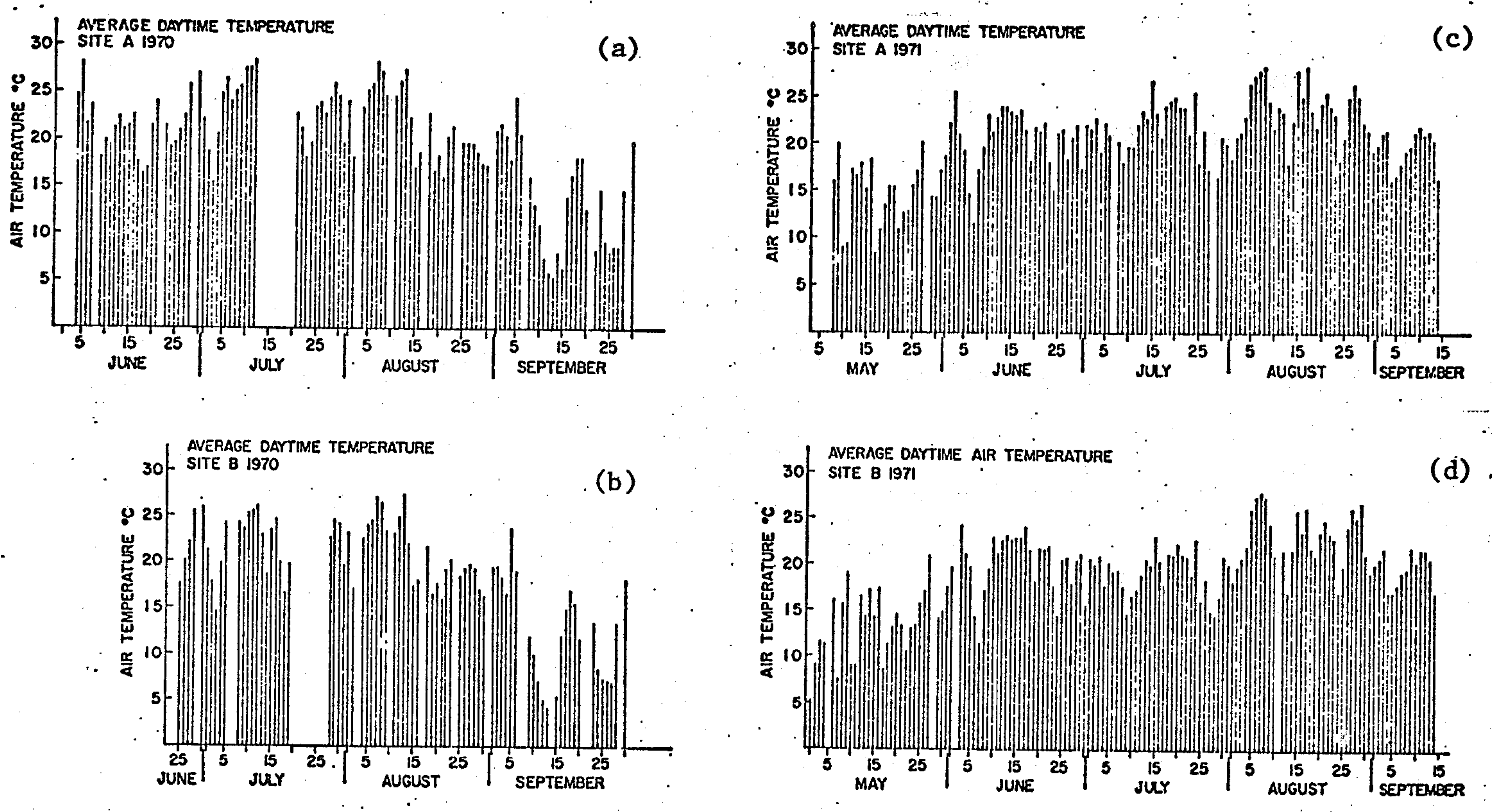


Figure 19 Average daytime air temperature at 1 m in the *Phragmites* canopy; (a) Site A, 1970, (b) Site B, 1970, (c) Site A, 1971, (d) Site B, 1971

TABLE III Average daytime air temperature (^{o}C) for the summer months, 1970

	Site A		Site B				
Month	mean	s.d.	mean	s.d.	diff.	t	Sig. p <
June	21.49	3.05					
July	23.64	3.79	22.37	3.35	1.25	6.65	0.001
August	21.54	3.77	20.71	3.57	0.83	9.10	0.001
September	14.07	5.72	12.69	5.46	1.38	12.53	0.001

TABLE IV Average daytime air temperature (^{o}C) for the summer months, 1971

	Site A		Site B				
Month	mean	s.d.	mean	s.d.	diff.	t	Sig. p <
May	14.65	3.32	14.37	3.17	0.28	1.77	0.05
June	20.31	3.13	20.06	3.10	0.25	2.46	0.025
July	21.51	2.55	19.16	2.28	2.19	11.99	0.001
August	23.42	3.01	22.81	3.00	0.61	5.58	0.001
September (1-14)	19.49	1.95	19.79	1.83	-0.30	-2.96	0.01

The mean monthly daytime temperatures in 1971 are presented in Table IV. As in 1970, temperatures at Site A were significantly higher ($p < 0.05$) than those at Site B for May, June, July and August but the differences were again small, the greatest difference being 2.2°C in July. In summary, the average daytime air temperature in the Delta Marsh in 1970 and 1971 exceeded 20°C in June, July and August, the latter being the warmest month with an average of 22.1°C.

(b) Temperature profiles

To relate the mean daytime air temperatures recorded on the hygrothermograph(T_a) to air temperatures at other levels within the *Phragmites* canopy and to soil temperatures, the average daytime temperature at the soil surface (0 cm), -10 cm, -25 cm and at 1 m, 2 m and 3 m were calculated from the temperature data recorded with thermisters. The mean daytime temperature (Site A) at each height was calculated for July, August, and September, 1970 (Figure 20a).

Differences between the daytime temperature recorded at 1 m, 2 m and 3 m were very small (Table V), but were statistically significant in most cases. The temperature was highest at 2 m which was slightly above the *Phragmites* canopy.

Because air movement within the canopy was low, one would expect within-canopy temperatures to be higher than those above the canopy. The reason they are not can be attributed to shading by the upper leaves of *Phragmites* and dissipation of heat by evapotranspiration.

A comparison was also made between temperatures recorded by the hygrothermograph (T_a) and by a thermistor probe mounted at a

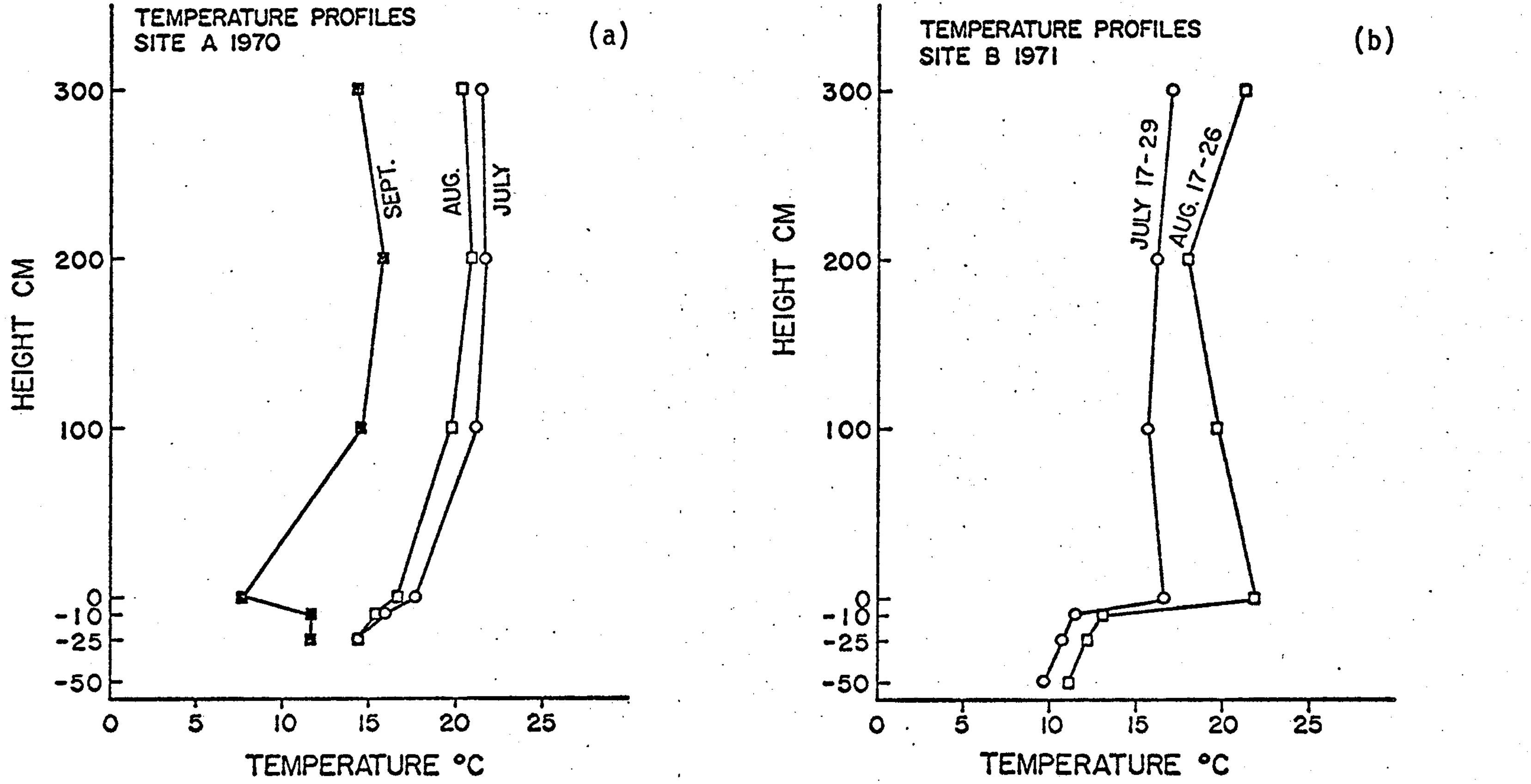


Figure 20 Mean daytime temperature profiles; (a) Site A, 1970, (b) Site B, 1971

TABLE V Mean difference between average daytime air temperatures at different heights, Site A, 1970

	Month	n	Mean Difference °C	s.d.	t statistic	Sig. p <
3 meters	July	11	-0.21	0.37	- 1.90	0.05
vs.	August	22	-0.51	0.36	- 6.53	0.001
2 meters	September	22	-1.46	0.50	-13.79	0.001
3 meters	July	11	-0.59	2.92	- 0.67	N.S.
vs.	August	22	0.64	0.53	5.62	0.001
1 meter	September	22	-0.28	0.72	- 1.81	0.05
3 meters	July	11	-1.09	1.39	- 2.62	0.025
vs.	August	22	-1.22	0.78	- 7.35	0.001
T_a	September	22	-0.17	0.81	- 0.97	N.S.

TABLE VI Mean difference between average daytime air temperatures at different heights, Site B, 1971

	Month	n	Mean Difference °C	s.d.	t statistic	Sig. p <
3 meters vs.	July 17-29	9	0.85	1.51	1.69	N.S.
2 meters	August 17-26	10	3.29	0.97	10.77	0.001
3 meters vs.	July 17-29	9	1.38	1.47	2.81	0.025
1 meter	August 17-26	10	1.6	0.45	11.26	0.001
3 meters vs.	July 17-29	9	-0.26	1.14	- 0.69	N.S.
T_a	August 17-26	10	1.30	1.27	3.24	0.01

height of 3 m at Site A to justify the use of thermograph temperatures in later analyses. The results show that average daytime temperatures recorded by the thermograph were slightly higher than those recorded by the 3 m thermistor. This similarity was expected in view of the small temperature differences between the 1 m and 3 m heights in the profile analysis.

In contrast with the temperature profiles at Site A, temperatures at a height of 2 m at Site B (Figure 20b) were slightly lower than those at 3 m. The difference (Table VI) was not statistically significant in July but there was a highly significant difference ($p < 0.00$) of 3.29°C in August. A high rate of transpiration at the 2 m height could have caused the observed temperature lowering. This being the boundary zone between the atmosphere and the plant canopy, one would expect transpiration to be higher than at other levels in the vegetation. However, this suggestion is not supported by the July temperature profile.

Wind speeds for the two periods could explain the dissimilar profiles as the average windspeed in July (Table X, p.101) was higher than in August, and increased turbulence could have had an equalizing effect on temperatures within the canopy.

Temperatures at the soil surface were higher at Site B in relation to the above ground profile than at Site A. This was probably a result of the drier soil surface at Site B with a lower heat capacity than the moist surface at Site A. No measure of the moisture content of surface litter was obtained and comparisons were made on the basis of qualitative observations and the soil moisture determinations in September 1971.

In comparing temperatures above the vegetation (i.e. 3 m) with hygrothermograph temperatures (T_a), no significant difference was observed in July and a small but statistically significant difference of 1.3°C was found in August. This indicates that air temperatures recorded by the hygrothermograph can be used in later correlations.

(c) Lysimeter soil temperatures

The mean difference in daily soil temperatures between undisturbed soil and the lysimeter was determined to compare the conditions within the lysimeter with those in the stand. On the average, soil in the lysimeter was warmer than in the stand (Table VII). The greatest mean difference 1.97°C, was observed at the 18 cm depth while the difference in surface temperatures was 0.63°C. All differences were significant ($p < 0.001$). The lysimeter monolith had a uniform soil temperature, with no detectable differences near the periphery (Table VIII).

4. Wind Speed

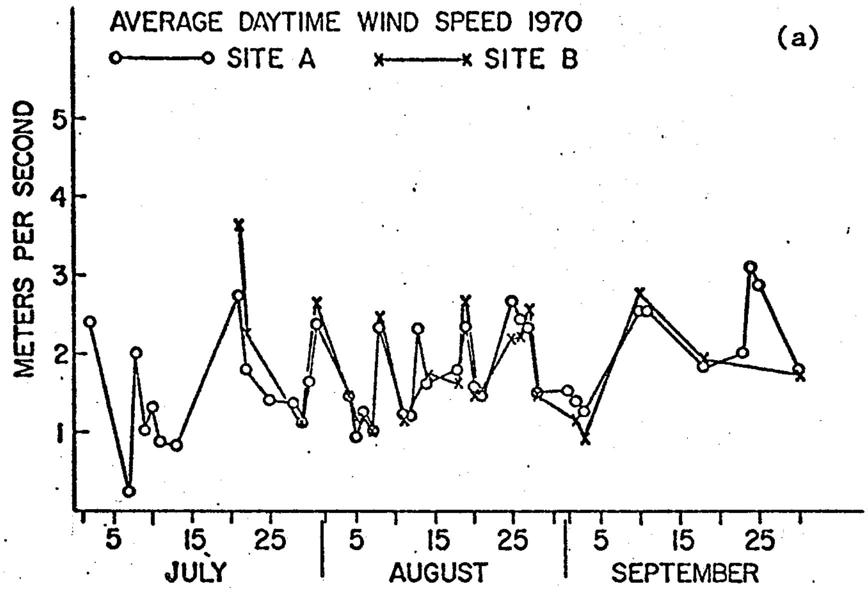
The mean daytime wind speed was very similar for the two sites in 1970 (Figure 21a) and ranged from 0.25 m sec^{-1} at Site A on July 7 to 3.64 m sec^{-1} at Site B on July 21. On the majority of the days it averaged from 1 to 3 m sec^{-1}. The results of a paired t-test (Table IX) show that the differences between the two sites were not significant.

TABLE VII Mean difference between the average daily soil temperature in the stand and in lysimeter 1B

Depth	n	Stand-Lysimeter Mean Difference °C	s.d.	t statistic	Sig. p <
Surface	59	-0.63	0.59	-8.27	0.001
-18 cm	58	-1.97	1.68	-8.92	0.001
-37 cm	58	-1.60	1.33	-9.14	0.001

TABLE VIII Mean difference between the average daily soil temperature in the periphery and at the center of the soil monolith lysimeter 1B

Depth	n	Outside-Center Mean Difference °C	s.d.	t statistic	Sig. p <
-18 cm	59	0.02	0.40	0.38	N.S.
-37 cm	59	-0.07	0.12	-4.37	0.001



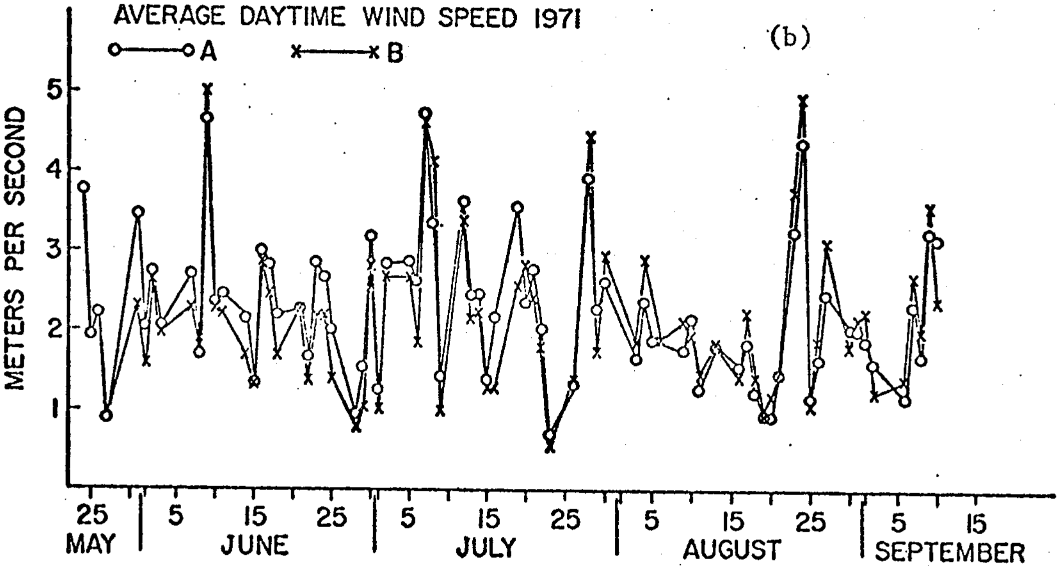


Figure 21 Average daytime windspeed; (a) Sites A and B, 1970, (b) Sites A and B, 1971

TABLE IX Monthly means of average daytime wind speed (meters per second), 1970

	Site A		Site B				
Month	mean	s.d.	mean	s.d.	Diff.	t	Sig. p <
July	1.51	0.69					
August	1.74	0.55	1.74	0.55	0.0006	0.01	N.S.
September	1.77	0.49	1.70	0.73	0.07	0.64	N.S.

TABLE X Monthly means of average daytime wind speed (meters per second), 1971

	Site A		Site B				
Month	mean	s.d.	mean	s.d.	Diff.	t	Sig. p <
June	2.36	0.78	2.09	0.87	0.26	4.82	0.001
July	2.50	0.99	2.33	1.13	0.18	1.87	0.05
August	1.88	0.81	2.05	0.97	-0.17	-3.06	0.005
September (1-14)	2.14	0.80	2.20	0.79	-0.05	-0.30	N.S.

The mean daytime wind speed in 1971 (Figure 21b) were generally higher than in 1970 ranging from 0.54 m sec^{-1} on July 23 to 5.0 m sec^{-1} on June 9 at Site B. As in 1970, the wind speed mostly fell in the range of 1 to 3 m sec^{-1}. The wind speed was generally higher at Site A than at Site B except in August.

The average daytime wind speed for each month (Table X) shows the same results; slightly higher average wind speed at Site A in June and July but slightly higher at Site B in August. Although the differences were statistically significant ($p < 0.05$), they were less than 0.26 m sec^{-1}.

The significance of small differences is not known but it shows that the two sites did have microclimatic differences. This could affect evapotranspiration rates if evapotranspiration had a large dependence on the wind factor.

5. Relative Humidity

The range in the mean daytime relative humidity (RH) for 1970 (Figure 22 a and b) was 50 percent to 100 percent at both sites. The mean daytime relative humidity was similar at Sites A and B on a daily basis.

The average RH for each month (Table XI) was only slightly higher (less than 4% RH) at Site B than at Site A but statistically significant at $p < 0.005$.

Although the statistical significance of the data is evident, the actual difference of 4 percent was below the ±5 percent accuracy of the instrument and therefore of no consequence. The average daytime relative humidity was lowest in August at 71 percent

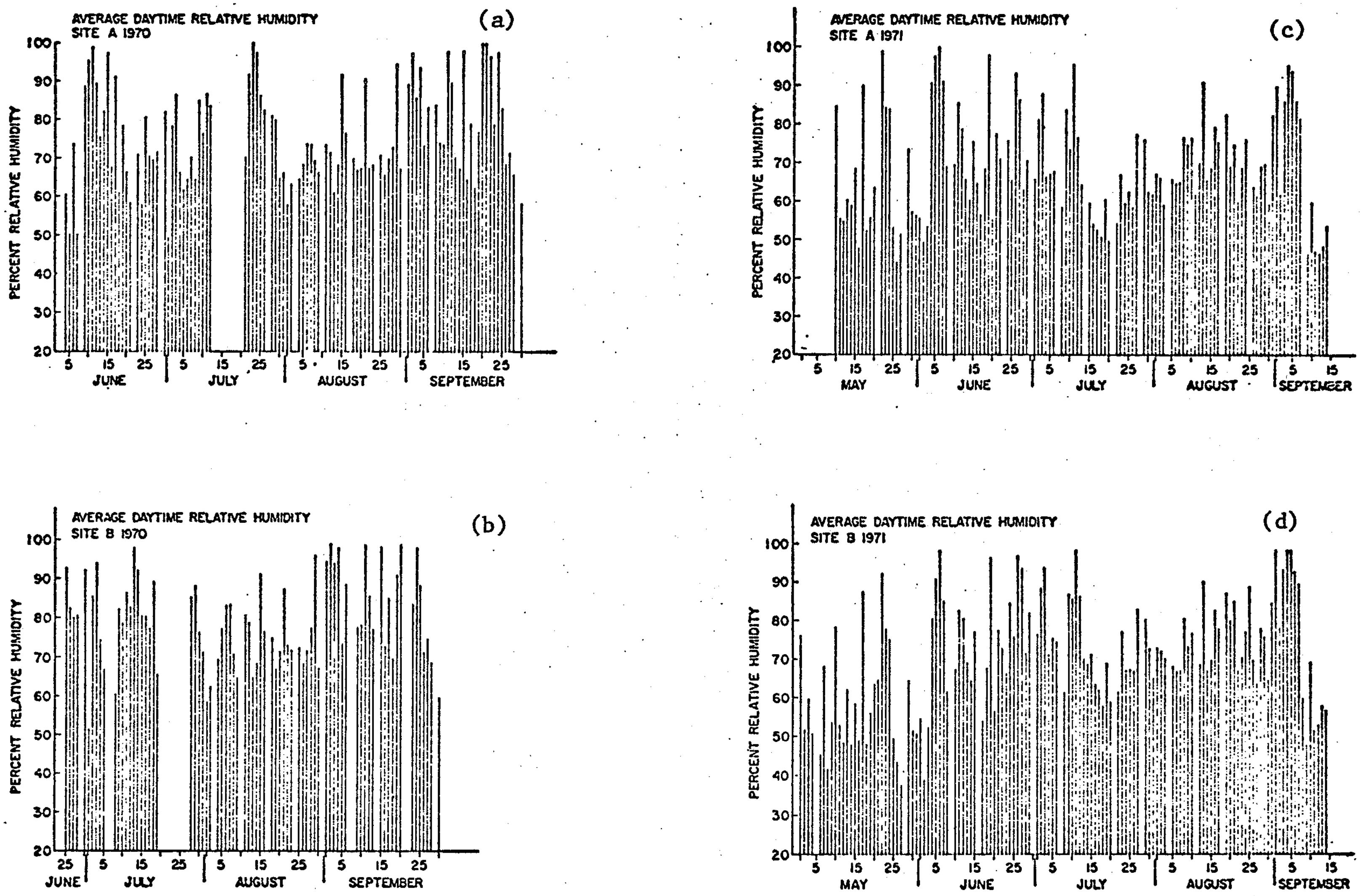


Figure 22 Average daytime relative humidity; (a) Site A, 1970, (b) Site B, 1970, (c) Site A, 1971, (d) Site B, 1971

TABLE XI Monthly means of average daytime relative humidity (percent) in 1970

	Site A		Site B				
Month	mean	s.d.	mean	s.d.	Diff.	t	Sig. p <
June	74.5	14.3					
July	73.6	11.4	77.4	11.5	3.8	3.15	0.005
August	71.3	8.9	74.2	8.8	2.9	4.04	0.001
September	81.8	12.8	84.3	11.7	3.8	4.91	0.001

TABLE XII Monthly means of average daytime relative humidity (percent) in 1971

	Site A		Site B				
Month	mean	s.d.	mean	s.d.	Diff.	t	Sig. p <
May	64.7	15.6	59.6	15.2	5.0	4.91	0.001
June	73.9	14.9	74.3	15.3	0.4	0.31	N.S.
July	66.3	11.5	73.6	10.9	7.3	13.82	0.001
August	70.3	7.7	74.1	7.3	3.8	5.66	0.001
September (1-14)	68.7	19.8	75.5	20.1	6.8	6.49	0.001

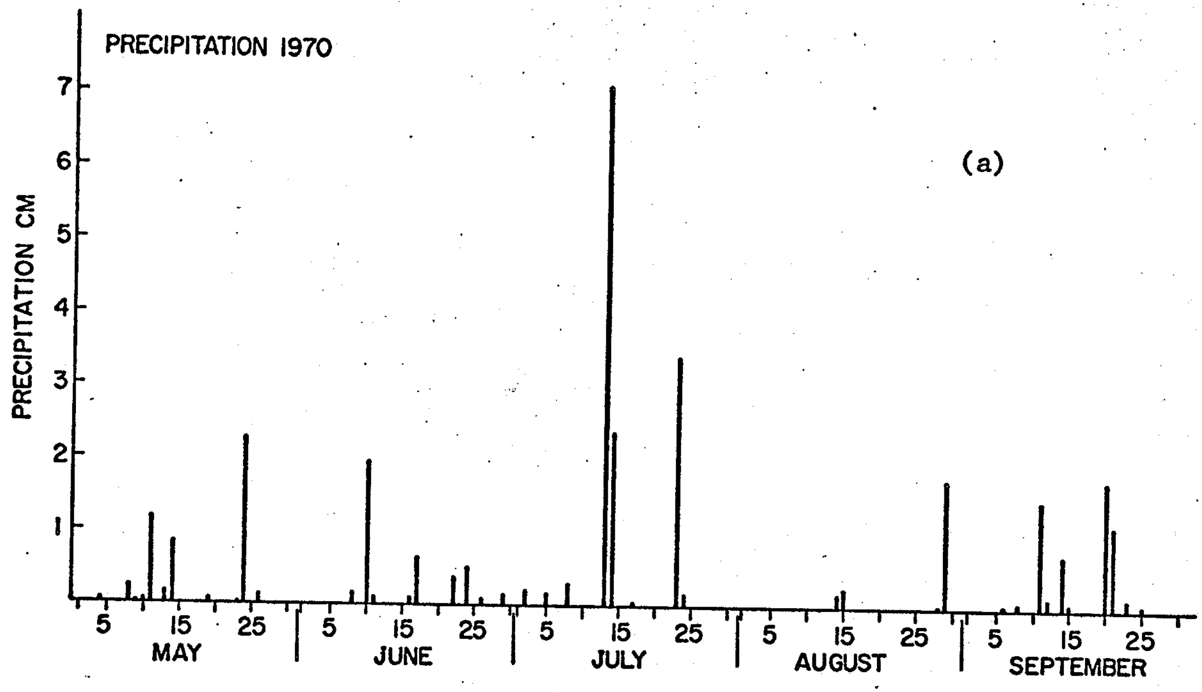
to 74 percent.

In 1971, the lowest average daytime RH was 44 percent at Site A (Figure 22c) on May 26 and 37 percent at Site B (Figure 22d) on to May 27. As in 1970, the majority of days had a mean RH range of 50 percent to 100 percent. In general, average daytime RH was lowest in July and significantly higher ($p < 0.001$) at Site B than at Site A (Table XII).

Because wind is the agent which dissipates water vapor released by evapotranspiration, differences in wind ventilation may account for the differences in relative humidity between the two sites. The wind ventilation of the sites was probably similar in May before the plants began to grow and the relative humidity would be determined primarily by moisture conditions at the soil surface. Site A being wetter, had a higher relative humidity. From July to September, Site B had a greater amount of vegetation (based on the leaf area index) and was probably more resistant to wind ventilation than Site A. This would allow the water vapor to accumulate in larger concentrations at Site B. June appeared to be a month of transition when the water vapor concentrations in the air were determined by the combined effects of the wetness of the soil and the wind ventilation.

6. Precipitation

Precipitation in the Delta Marsh in the summer is quite irregular (Figures 23 a and b) and comes mostly from localized thunder showers. In 1970 and 1971, the incidence of rainfall was low in the month of August compared with other months. The precipitation frequency was high in June and July of 1971 when measurable amounts of rain were



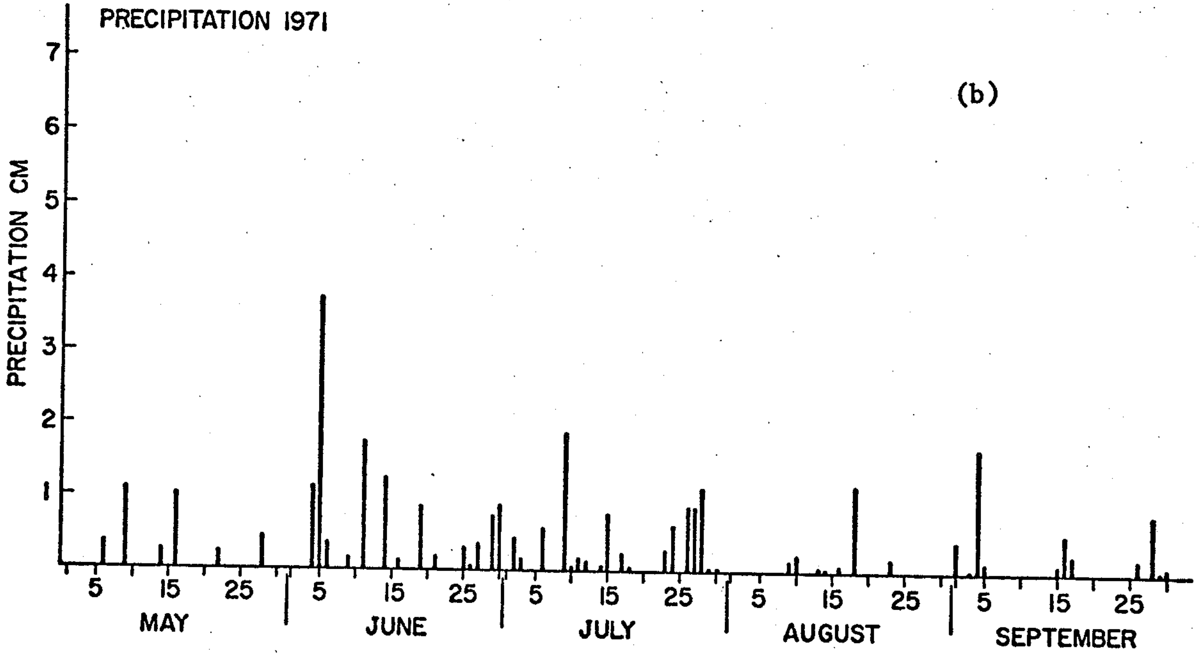


Figure 23 Precipitation in the Delta Marsh (a) 1970, (b) 1971

recorded on 14 and 18 days of each month respectively. The maximum precipitation for a 24-hour period in the two seasons was 7.1 cm on July 13, 1970.

The total seasonal rainfall was approximately 2 cm less in 1971 than in 1970 (29.0 cm vs. 30.5 cm Table XIII). The largest monthly aggregate, 13.7 cm, fell in July 1970; over half of it occurred in a single storm on July 13. In 1971, June had the largest monthly total with 11.9 cm while the July total was next at 8.3 cm. Precipitation was lowest in August of both years, 2.2 cm in 1970 and 1.9 cm in 1971.

B. Analysis of Shallow Ground Water Table Fluctuations

In the analysis of water table fluctuations, the formula derived by White [1932] has a strong theoretical basis. The principles have been applied to numerous water table records in Saskatchewan and the resulting evapotranspiration estimates were quantitatively sound [Meyboom, 1967]. Using this formula, daily evapotranspiration estimates (E_{WT}) were computed from the water table fluctuations recorded at Sites A and B in 1970 (Figures 24 a and b). At Site A, standing water was present until August 2 except on July 1 and 2 when the level dropped slightly below the soil surface. When there was standing water on the soil surface, the water level fluctuated in response to that in the open channels and bays of the marsh which was dependent in turn on the level of Lake Manitoba. Lake Manitoba is large and wind tides are common, with high water levels being recorded along the south

TABLE XIII Precipitation in 1970 and 1971 monthly and seasonal totals

	Precipitation cm	
Month	1970	1971
May	5.0	3.4
June	4.0	11.9
July	13.7	8.3
August	2.2	1.9
September	5.5	3.5
TOTAL	30.5	29.0

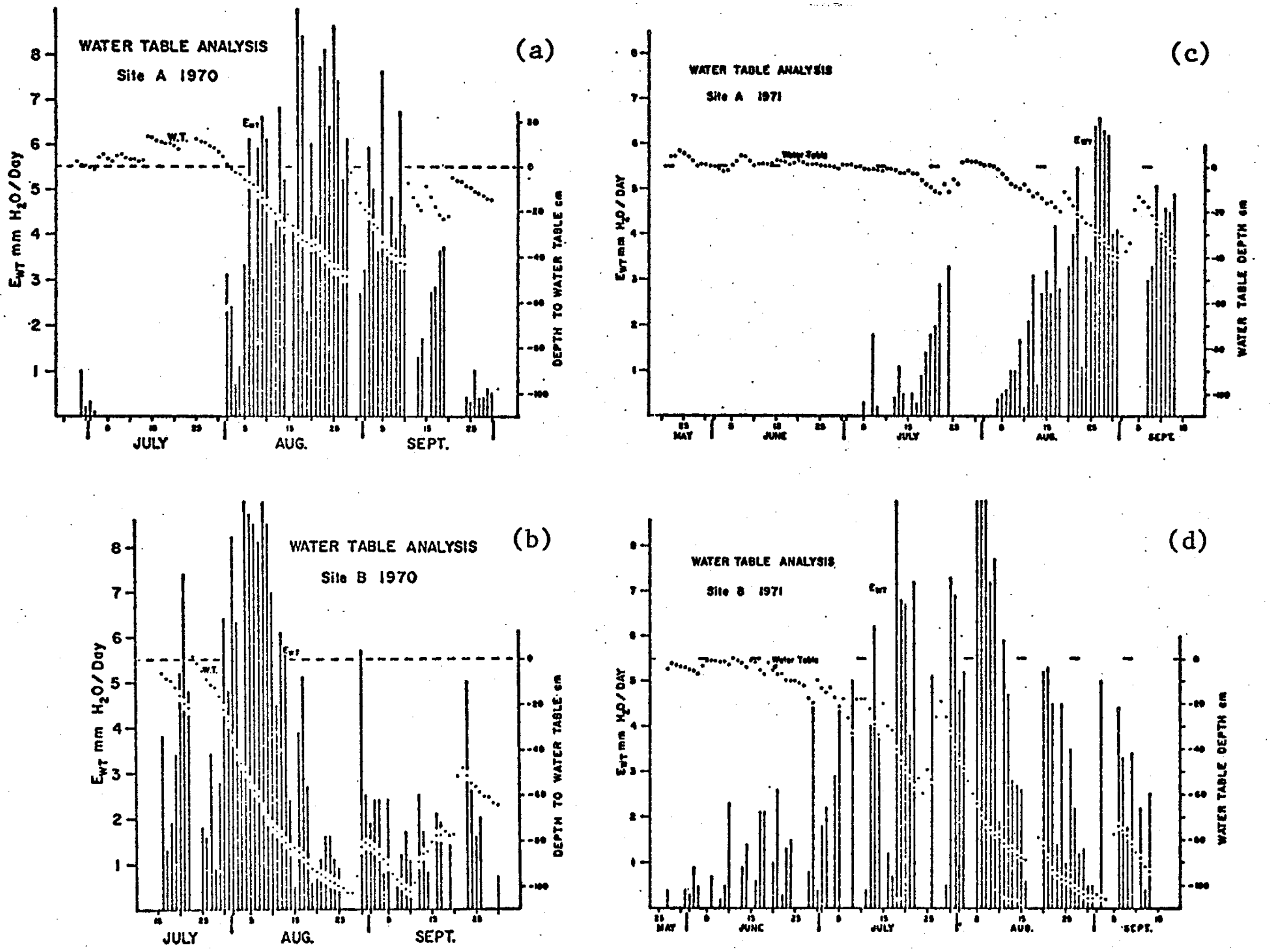


Figure 24 Daily estimates of evapotranspiration from water table fluctuations (E_{WT}) and the position of the water table (W.T.) in relation to the soil surface (0 cm); (a) Site A, 1970, (b) Site B, 1970, (c) Site A, 1971, (d) Site B, 1971

shore during prolonged north winds and low levels when there is a south wind. These fluctuations occur independently of evapotranspiration and as the effects of the marsh fluctuations on the water levels at Site A could not be quantified, the water levels recorded during the time when water covered the soil surface could not be related to evapotranspiration. Nor could the data collected in the first day or two after a rain be used because of fluctuations which occur while the water table is stabilizing at its new level, hence the absence of data immediately following a rain. Days on which precipitation occurred can be identified by the abrupt rise in the water table.

At Site A, the magnitude of E_{WT} increased with increasing water table depth. Values were below 4 mm H_2O day^{-1} from August 1 to 5 when the water table was between 0 and -5.8 cm. On August 17, when the water table was at -30 cm, the E_{WT} was 10.1 mm. A similar pattern is noted after August 30 when the water table rose through precipitation. Values of E_{WT} were initially low but increased as the water table decreased again. The overall pattern of the estimate shows an increase until August 17 followed by decreasing values until September 30.

At Site B (Figure 24b) E_{WT} increased to a peak of 9.4 mm H_2O day^{-1} on August 4 when the water table was at -49.8 cm and then decreased to values less than 2 mm H_2O day^{-1} when the water table was below -90 cm. The rise in the water table on August 30 caused higher E_{WT} values, which gradually decreased again as the water table decreased The seasonal pattern of E_{WT} differed between the two sites, the peak occurring earlier at Site B than at Site A. It is apparent from these data that the response of E_{WT} to the water table depth obscured the dependence of the fluctuations on evapotranspiration.

In 1971 the water level at Site A (Figure 24c) was initially lower than in 1970, and by July 5 had dropped below the soil surface. Normally, as soon as it fell below the soil surface, the magnitude of the daily drop increased because of the specific yield of the soil. In this case, it fluctuated in the upper 3 cm of the soil until July 17 before the "normal drop" occurred. Resistance to lateral flow through the highly organic soil surface (Table XVI, p. 130) must have been low, allowing rapid replacement of water used in evapotranspiration from adjacent areas of open water.

On July 18, E_{WT} began to increase in magnitude but decreased again when rainfall on July 26, 27 and 28 raised the water table. Peak values of E_{WT}, greater than 6 mm H_2O day^{-1}, were recorded from August 26 to 30 when the water table was between -29 and -36 cm. This is consistent with the depth where E_{WT} peaked at Site A in 1970. Other high values were recorded from September 9 to September 13 following a precipitation induced rise in the water table on September 3, 4 and 5. During the study period, E_{WT} increased gradually to the peak of 6.6 mm H_2O day^{-1} on August 27 and then showed a slight decrease to September 13.

The water table at Site B (Figure 24d) rose to the soil surface only on July 11 in 1971. As in 1970, the estimate of water use by the plants increased with decreasing water table levels. The high value on July 18 was probably caused by water table stabilization processes following the rain three days earlier on July 15. Therefore, the true peak in E_{WT} probably occurred on August 6 when E_{WT} was 10.1 mm H_2O day^{-1}. On that date, the water table was -68.4 cm below the soil surface. As in 1970, E_{WT} decreased as the water table dropped below -90 cm. There is evidence of a seasonal increase in E_{WT} until August 6 followed by a decrease to September 13 which is consistent with the seasonal cycle in evapotranspiration, but the response of E_{WT} to the position of the water table is still evident.

C. Soil Characteristics

1. Particle Size Analysis

Results from the soil particle size analysis for five 20 cm zones were pooled to determine mean sand, silt and clay percentages for each site (Figure 25). Sand is defined here as those soil particles ≥ 62 microns (μ), silt particle ranged from $2\,\mu$ to $62\,\mu$ and clay $< 2\,\mu$.

Both sites had a high percentage of sand (70-80%) in the upper 20 cm of the soil. In the next zone (21-40 cm) at Site A, the percentage of silt increased from 11 percent to 51 percent and clay from 10 percent to 14 percent. The proportion of clay size particles in the soil below -40 cm was fairly constant at about 40 percent while the silt and sand fractions were about 50 percent and 10 percent respectively. At Site B, the percentages of the three fractions were fairly constant below -20 cm, at 22 to 24 percent clay, 26 to 30 percent silt and 47 to 51 percent sand.

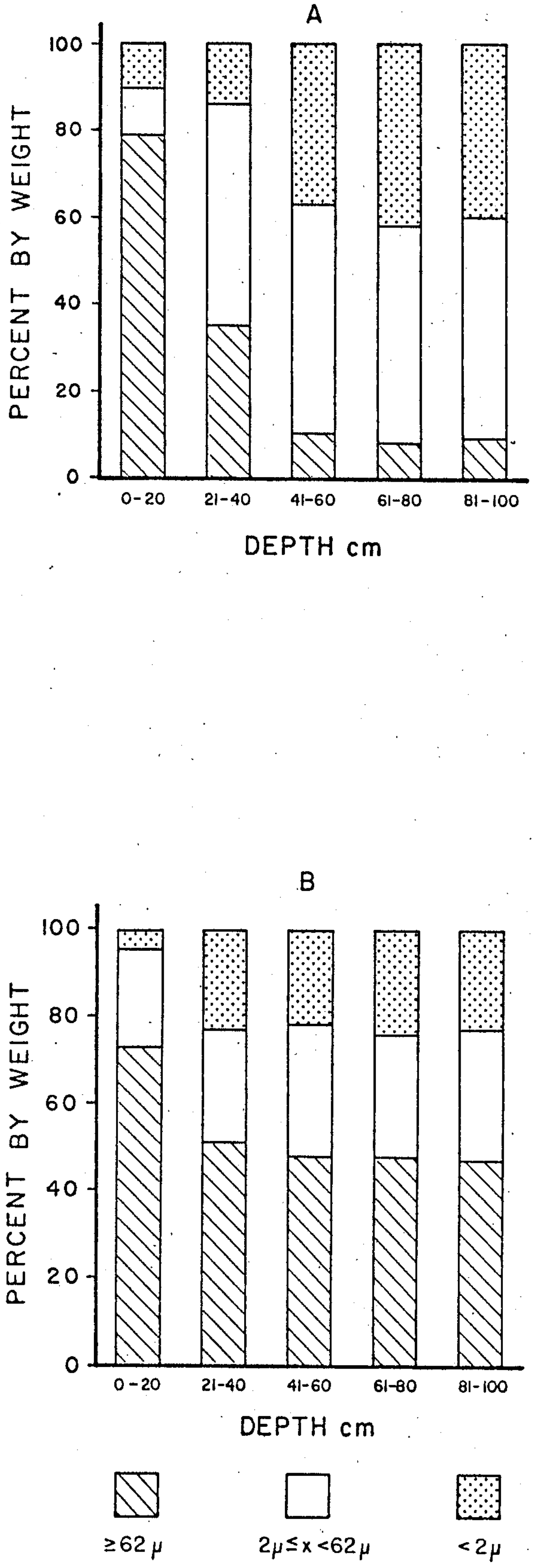


Figure 25 Cumulative bar graph of particle size distribution in the upper 100 cm of the soil at Site A and Site B

2. Specific Yield[1]

The U.S.D.A. textural triangle was used to determine the soil classifications for each zone. The specific yield figures were obtained from Meyboom [1967, p. 22]. Table XIV lists the soil classes and the estimated readily available specific yield for each zone. The water table depth ranged from 0 to -40 cm at Site A and 0 to -100 cm at Site B and the specific yield values for those soil zones ranged from 8.25 percent to 9 percent. The readily available specific yield of 9 percent was used in White's formula (see water table analysis p. 49) because the range of a specific yield values was small and computations were simplified by this choice.

3. Soil Moisture

Data on the moisture content of the soil zones to a depth of 1 m are presented in Table XV. On September 2, 1971 when the samples were collected, the water table at Site A was 39 cm below the soil surface. The moisture content in the saturated zone of the soil, that is, -41 to -100 cm ranged from 52.1 percent to 45.1 percent by weight. In the 21 to 40 cm zone, it was 84.4 percent and in the surface zone (0-20 cm) 327.9 percent. The soil near the surface i.e. in the two upper zones had a higher organic content (Table XVI) which increases the water holding capacity.

At Site B, the 81-100 cm zone was saturated when the samples were obtained, the water table being 83 cm below the surface; the

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[1] Specific yield is the capacity of the soil to yield water under the pull of gravity.

TABLE XIV U.S.D.A. soil classification for a 100 cm soil profile at Site A and Site B and the corresponding readily available specific yield from Meyboom (1967)

Depth	Site A		Site B	
cm	Classification	Specific Yield	Classification	Specific Yield
0-20	Sandy loam	8.25%	Sandy loam	8.25%
21-40	Silt loam	9.00%	Sandy-clay loam	<8.25%
41-60	Silty clay loam	6.25%	Loam	9.00%
61-80	Silty clay	6.25%	Sandy-clay loam	<8.25%
81-100	Silty clay loam	6.25%	Loam	9.00%

TABLE XV Mean soil moisture as a percentage of oven-dry weight in the 5 sampling zones at Site A and Site B on September 2, 1971

Depth	Site A			Site B		
cm	mean%	s.d.	(n=12)	mean%	s.d.	(n=15)
0-20	327.9	58.93		88.3	23.39	
21-40	84.4	23.89		30.2	2.9	
41-60	52.1	2.12		29	2.13	
61-80	49	1.88		28.5	1.86	
81-100	45.1	2.57		27.6	2.58	

moisture content was 27.6 percent. There was no reduction in the moisture content above the water table but rather a slight increase to 30.2 percent for the 21 to 40 cm zone. In the 0-20 cm zone, with a higher organic content, the soil moisture averaged 88.3 percent.

These data show that there was no reduction in the moisture content of the soils above the water table at either site.

Higher soil moisture contents were found at Site A than at Site B even in the saturated zones (Table XV). The soils at Site A appeared to have a type of crumb structure (author's observation) which would result in a higher storage capacity than the soils at Site B which had a more compact appearance.

4. Soil Organic Matter

The percent organic matter for the soils at each site is listed in Table XVI. The surface zone at Site A was highly organic, 54.1 percent as compared with that at Site B, 3.6 percent. Observations at the time of sampling indicate that Site B had a shallow layer of humus approximately 5 cm at the surface with a rapid transition to a "b" horizon. Inadequate mixing of the sample prior to analysis may account for the low organic percentage (10 to 15% would be more realistic). Below -41 cm the two sites were similar, both having low organic contents.

TABLE XVI Soil organic matter expressed as a percentage of oven-dry weight

Depth	Site A		Site B	
cm	mean %	s.d.	mean %	s.d.
0-20	54.1	0.71	3.6	1.13
21-40	9.8	2.12	3.3	0.0
41-60	3.7	0.14	1.9	0.42
61-80	2.3	0.07	1.2	0.21
81-100	1.3	0.28	0.8	0.07

D. Evaporation, Transpiration and Evapotranspiration in *Phragmites*

In 1970, evaporation (E) at Site A (Figure 26a) ranged from 0.0 to a high of 3.8 mm H_2O day^{-1} in mid August. The lysimeters were not sensitive enough to measure the amounts less than 0.50 mm H_2O accounting for the fact that no evaporation was recorded on a number of days. General trends indicate daily E rates below 2 mm H_2O day^{-1}, the higher values occurring in late July and early August and decreasing rates until September 29.

In 1971, (Figure 26b) daily E varied between 0.0 and 3.13 mm day^{-1}. The seasonal trend was similar to that observed in 1970 but the June/July E rates were higher (>2 mm H_2O day^{-1}) than in late July and early August. As in 1970, evaporation was less than 2 mm day^{-1} from July 29 through September.

In 1970, transpiration (T_R) peaked in the second week of August, the highest rate being 4.8 mm day^{-1} on August 7 (Figure and 26a). It is possible that the true peak had occurred before the lysimeters were installed. T_R rates declined gradually through the remainder of August and were very low (<1 mm day^{-1}) on September 23, 24 and 29.

In 1971, the maximum T_R 4.5 mm day^{-1} was recorded on July 13 and the general trend of values supported the early August peak observed in the 1970 data. T_R rates in June were less than 2 mm day^{-1} while they exceeded 3 mm day^{-1} on 8 of 32 days in July and August.

It is evident that E and T_R respond in different ways through the season; the most evident example being the mid-summer peak in T_R

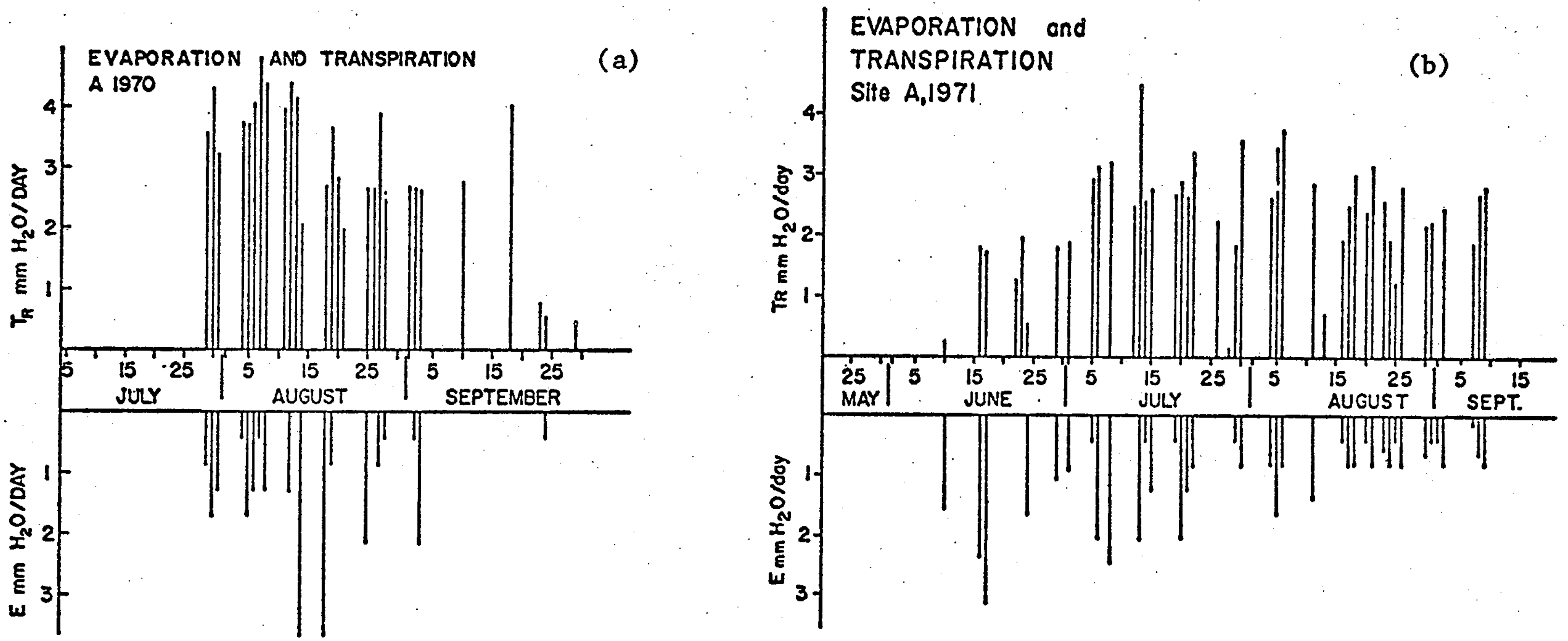

Figure 26 Daily evaporation and transpiration from lysimeter measurements, Site A; (a) 1970, (b) 1971

versus that in early summer for E. Individual days also had dissimilar responses, probably caused by microclimatic differences between the aerial portions of the *Phragmites* and the soil surface below the stand.

Evapotranspiration (E_T) from the *Phragmites* stand at Site A in 1970 (Figure 27a) reached a maximum of 6.5 mm day^{-1} on August 18 and a minimum 0.5 mm day^{-1} on September 29. Daily E_T was generally between 3 and 6 mm day^{-1} until the later part of September.

In 1971, the daily E_T had a low of 0.21 mm day^{-1} on July 28 and a high of 6.5 mm day^{-1} on July 13 (Figure 27b). The pattern of daily rates was similar to that for transpiration. E_T rates were lower than in 1970, falling in a range of 2 to 5 mm day^{-1} for most days. Mean T_R and E_T rates (Table XVII) show that in 1970, mean rates were consistently higher than for the corresponding months in 1971. The large discrepancy between the means for July 1970 and July 1971 was due in part to the fact that the mean for July 1970 was based on only 3 values obtained near month end. Comparable data was obtained in August of both years when T_R was 0.9 mm day^{-1} higher in 1970 than in 1971 and E_T was 1.3 mm higher. The September means are not comparable because the 1970 data was distributed over the whole month while the 1971 data only apply to the first ten days.

In spite of the differences, the ratio of T_R to E_T was similar for the two years. All July, August and September ratios expressed as a percentage, were in the 75 to 80 percent range. The ratio for June 1971 was significantly lower at 53.9 percent indicat-

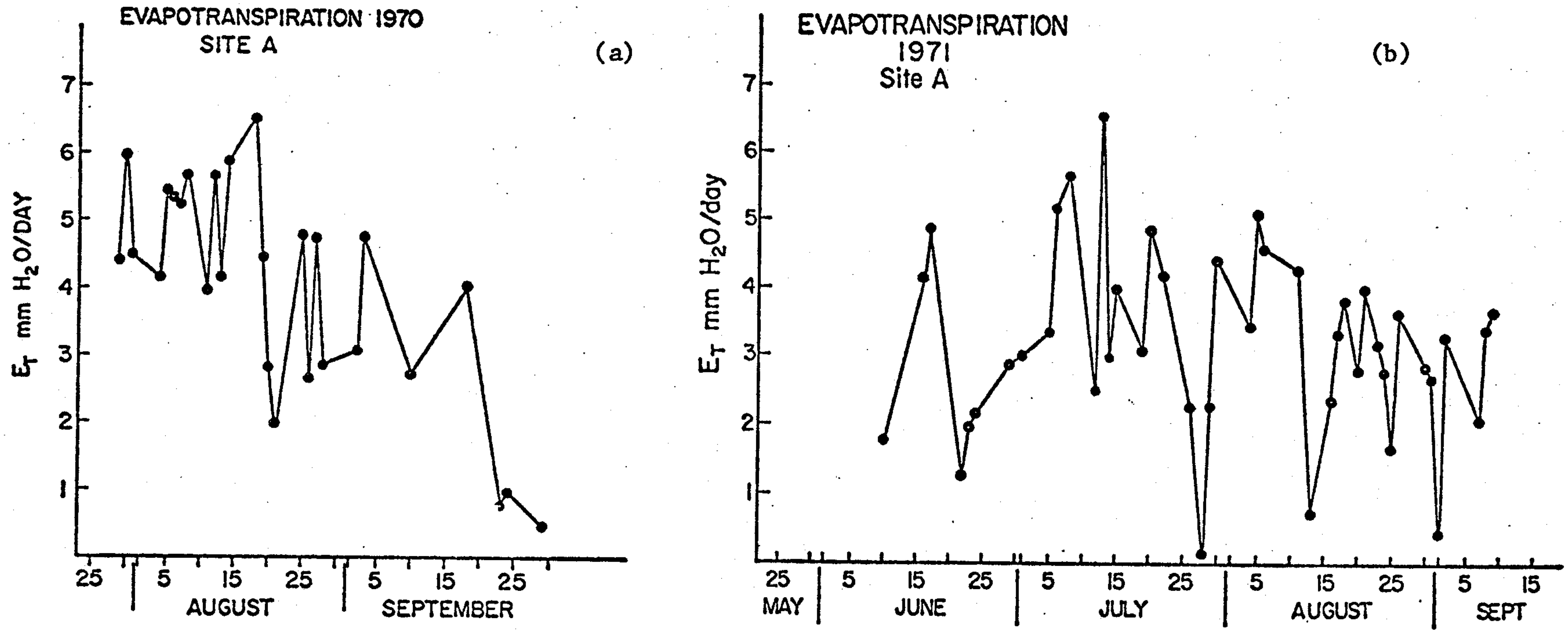

Figure 27 Daily evapotranspiration by *Phragmites* from lysimeter measurements, Site A; (a) 1970, (b) 1971

TABLE XVII Mean monthly transpiration and evapotranspiration at Site A in 1970 and 1971

		T_R(mm H_2O/day)		E_T(mm H_2O/day)		$\frac{\Sigma T_R}{\Sigma E_T}$ x 100
Month	n	mean	s.d.	mean	s.d.	%
July 70	3	3.7	0.55	5.0	0.89	74.4
August 70	17	3.4	0.88	4.5	1.29	76.1
September 70	5	2.5	1.24	3.1	1.42	80.8
June 71	6	1.3	0.72	2.4	1.01	53.9
July 71	13	2.7	0.98	3.6	1.69	73.9
August 71	15	2.5	0.79	3.2	1.12	77.6
September 71	5	2.0	1.14	2.5	1.32	77.5

ing that E and T_R contributed almost equal amounts to the total water use in that month.

Evaporation from the soil surface below the *Phragmites* at Site B (Figures 28a and b) was often lower than the sensitivity of the lysimeters. Because of this, no E was recorded on nearly 50 percent of the days in 1970 and 1971. Daily values ranged from 0.0 to 1.7 mm H_2O in both years, the maximum occurring on August 12 in 1970 and July 8 in 1971. With the exception of four or five days. E was generally below 1 mm day^{-1} in the two seasons. The data presented in Figures 28a and b does not show a detectable seasonal pattern, the day to day variability being as large as the seasonal.

The transpiration rates (upper portions of Figures 28 a and b) ranged from a low of 0.4 mm day^{-1} on September 29, 1970 to a high of 6.3 mm on September 18. The high T_R recorded on September 18 was not consistent with the seasonal pattern and it is obvious (Figure 28a) that the peak for the peak for the period after July 29, was 6.2 mm day^{-1} on August 14. The lowest T_R for this period was observed in the last part of September. About 50 percent of the daily T_R rates were in excess of 4.3 mm.

In 1971, the lowest T_R rate at Site B was 0.2 mm day^{-1} on July 28 and the highest was 5.7 mm on July 13. The seasonal trend in T_R indicates a rapid increase from June to mid-July followed by a gradual reduction in the rate through the remainder of the season. The median transpiration rate for the period indicated was 3.1 mm day^{-1}, 1.0mm lower than in 1970.

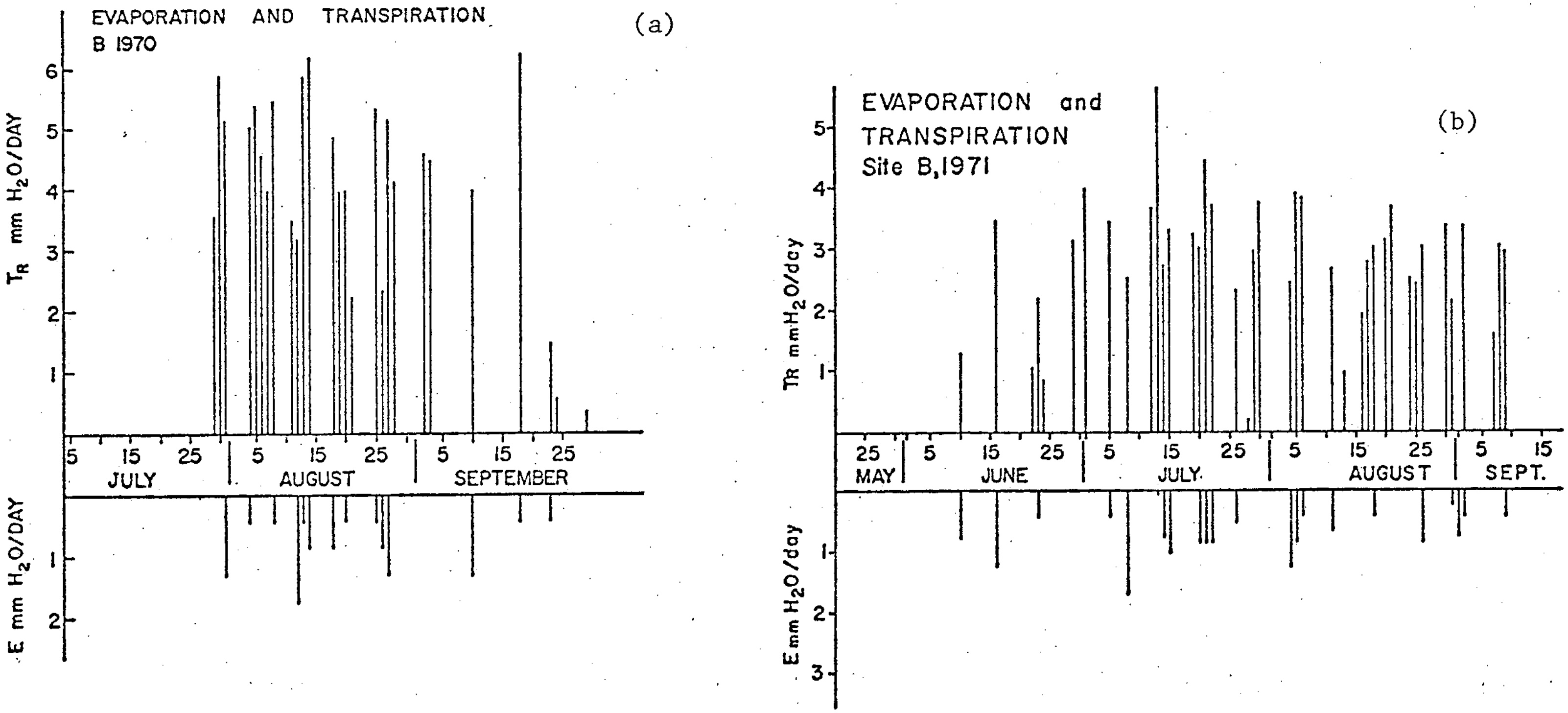

Figure 28 Daily evaporation and transpiration from lysimeter measurements, Site B: (a) 1970, (b) 1971

Daily evapotranspiration (E_T) reflected the strong contribution of transpiration, the trends being similar. In 1970, (Figure 29a) the maximum E_T, 7.1 mm day^{-1}, was recorded on August 14, while the minimum, 0.4 mm day^{-1} was observed on September 29. A large proportion of days had E_T rates in the range of 3 to 6 mm day^{-1}. In 1971, (Figure 29b) the maximum E_T recorded was 5.7 mm day^{-1} on July 13 and the lowest was 0.2 mm on July 28. On most days, evapotranspiration rates lay between 2 and 5 mm day^{-1}.

Mean T_R and E_T rates for 1970 and 1971 can only be compared for the month of August because the distribution of sampling dates in other months did not overlap (Table XVIII). The mean T_R August 1971 was 1.6 mm day^{-1} lower than in 1970 and the mean E_T was 1.8 mm day^{-1} lower. T_R and E_T was higher in July than in any other month but there were no significant differences between July and August rates.

In 1970, the T_R/E_T ratio expressed as a percentage was slightly higher than 90 percent. In 1971, this ratio ranged from 85 to 90 percent from July through September and was lowest in June at 83.1 percent.

Transpiration occurs almost entirely through the leaf surfaces, and given adequate ventillation, it should vary directly with the leaf area. The transpiration rate per unit leaf area per day at Site A (Figures 30 a and c) indicates that "normal" transpiration during the time after the plants reach maturity ranged from 8 to 19 ml dm^{-2} day^{-1} in 1970 and 8 to 15 ml dm^{-2} day^{-1} in 1971.

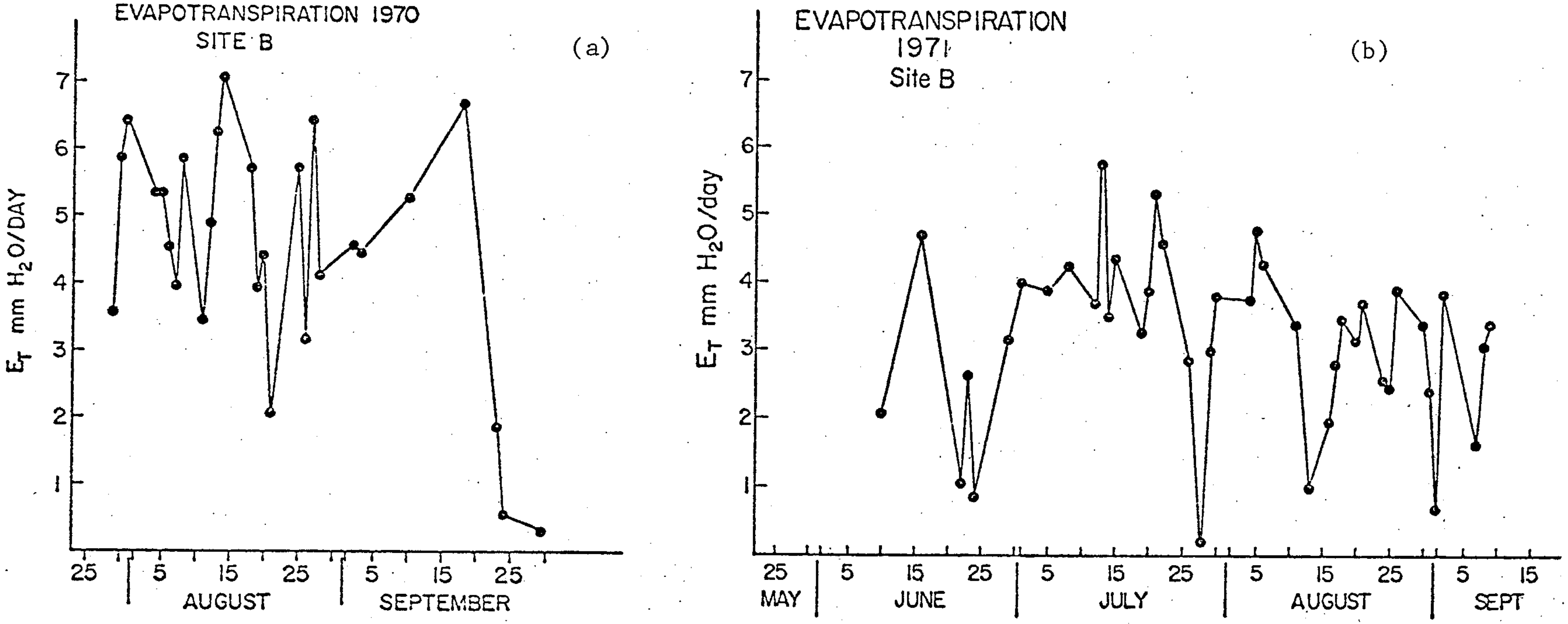

Figure 29 Daily evapotranspiration by *Phragmites* from lysimeter measurements, Site B; (a) 1970, (b) 1971

TABLE XVIII Mean monthly transpiration and evapotranspiration at Site B in 1970 and 1971

		T_R (mm H_2O/day)		E_T (mm H_2O/day)		$\frac{\Sigma T_R}{\Sigma E_T}$ x 100
Month	n	mean	s.d.	mean	s.d.	%
July 70	3	4.9	1.19	5.3	1.54	91.8
August 70	17	4.4	1.17	4.9	1.31	90.1
September 70	5	4.0	2.10	4.3	2.28	92.0
June 71	6	2.0	1.11	2.4	1.43	83.1
July 71	13	3.0	1.19	3.6	1.27	85.7
August 71	15	2.8	0.78	3.1	0.96	89.8
September 71	5	2.2	1.40	2.5	1.32	87.8

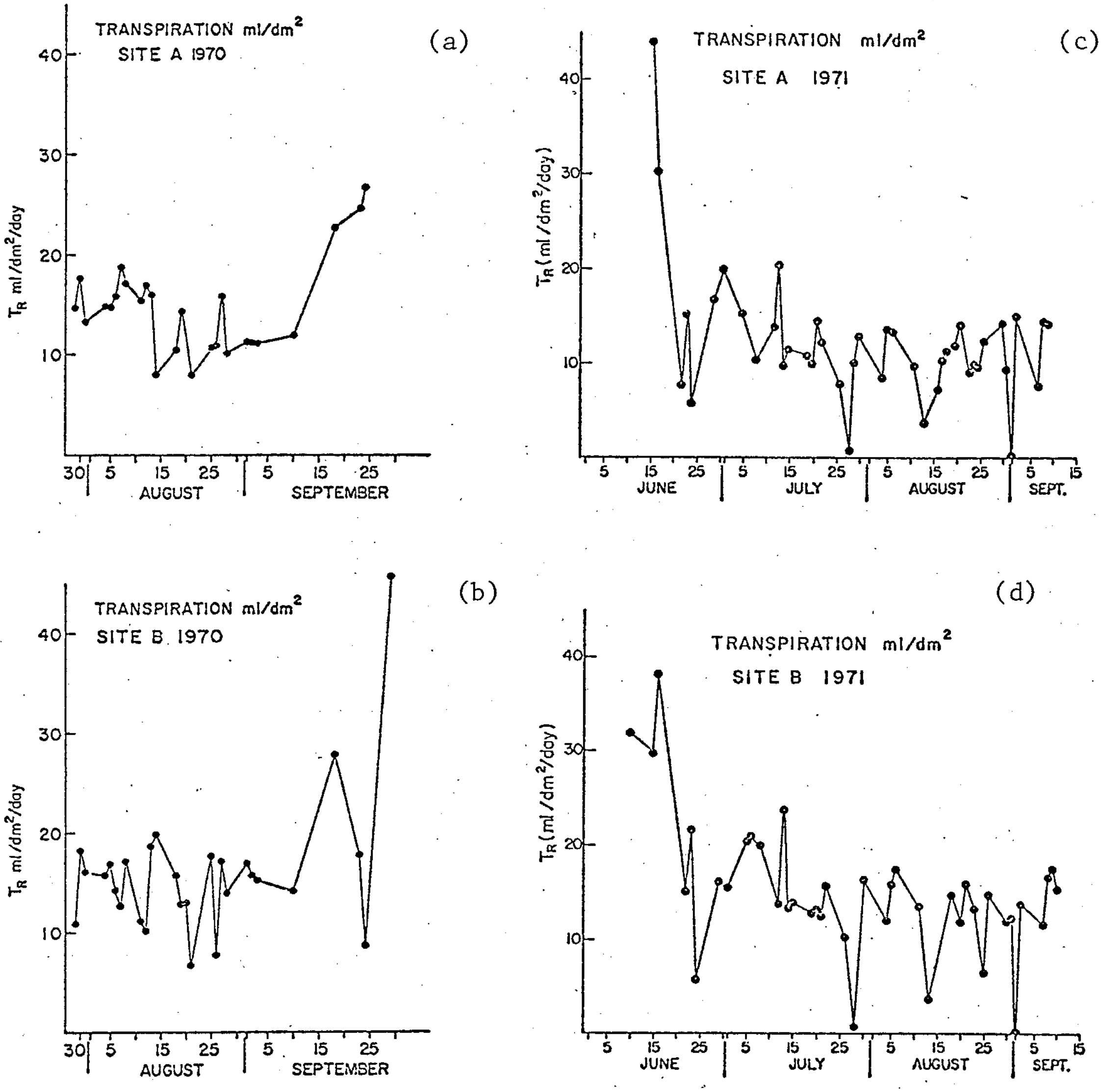

Figure 30 Transpiration per unit leaf area by *Phragmites;* (a) Site A, 1970, (b) Site B, 1970, (c) Site A, 1971, (d) Site B, 1971

Up to July 13 when the plants were nearing maximum leaf area, the rate was decreased from highs of 30 to 45 ml dm^{-2} day^{-1} in mid-June 1971. In contrast an increase in the unit leaf rate, occurred in late September (1970) being correlated with the senescence of leaf tissue. In summary, T_R per unit leaf area was indirectly associated with LAI during the rapid growth phase of the plants and during the period of rapid senescence at the end of the growing season.

At Site B (Figures 30b and d) the same phenomenon was observed. "Normal" summer T_R varied between 7 and 20 ml dm^{-2} day^{-1} in 1970 and between 8 and 18 ml dm^{-2} day^{-1} in 1971.

In general, the trends in evaporation, transpiration and evapotranspiration from Site A and Site B were similar. However, the evaporation rate was lower at Site B than at Site A and decreased through the season at Site A while showing no seasonal pattern at Site B. Daily T_R for the two sites had a similar seasonal pattern except that the peak occurred earlier at Site B (July 16) than at Site A (August 6). The average daily T_R was consistently lower at Site A than at B but the differences were small and not statistically significant. Average daily E_T was also lower at Site A in 1970 but again the differences were not significant. A larger percentage of E_T was accounted for by T_R at Site B (85-90%) than Site A (74-78%). The ratio of T_R/E_T expressed as a percentage was low in June 1971 at Site A (53.9%) while that at Site B (83.1%) was only slightly less than the summer range.

E. *Phragmites* Shoot and Stand Characteristics

1. Density

The density of *Phragmites* in the two seasons (Tables XIX and XX) ranged from 70.9 shoots m^{-2} at Site A in 1971 to 83.8 shoots m^{-2} at Site B. In 1970 the total density of plant species other than *Phragmites* in the stands was 34.9 plants m^{-2} and 33.0 plants m^{-2} at Site A and B respectively and in 1971 51.5 and 46.9 plants m^{-2}. The typical understory beneath the *Phragmites* included members of the Labiateae family, *Lycopus asper, Mentha arvensis* var. *villosa Stachys palustris* var. *pilosa* and *Teucrium occidentale*. *Urtica dioica* var. *procera* and *Cirsium arvense* were associated with the *Phragmites* at the drier site, B while *Chenopodium glaucum* var. *salinum* and *Sonchus arvensis* were found where the stand was not as dense. *Scholochloa festucacea* and *Carex atherodes* occurred along the borders of the stands and in small clones within the stand at Site A. Only 16.2 percent of the *Phragmites* shoots at Site A and 18.9 percent of those at Site B produced panicles in the 1971 season. Many of the shoots (10.8% at Site A and 18.2% at Site B) were damaged by the larvae of *Apamea* Ochs. a member of the Lepidoptera and this undoubtedly reduced the inflorescence production. The larvae bored into the stem and killed the apical bud when the shoots were about 1 m tall. More than 50 percent of the shoots in lysimeters 3B and 4B were damaged in the same way, and new monoliths had to be transplanted in their place.

TABLE XIX Species composition and plant densities in 1970

	Site A		Site B	
Plant Species	Shoots m^{-2}	s.d.	Shoots m^{-2}	s.d.
Phragmites communis	80.9	50.47	78.4	43.26
Scolochloa festucacea	1.6	6.27		
Carex atherodes	14.6	26.65		
Ranunculus sceleratus	1.1	3.92		
Lycopus asper	13.0	24.45	2.0	5.33
Stachys palustris			13.8	18.18
Teucrium occidentale	5.2	15.05	7.8	17.40
Cirsium arvense			6.4	8.78
Sonchus arvensis			3.0	7.37

TABLE XX Species composition and plant densities in 1971

	Site A		Site B	
Plant Species	Shoots m^{-2}	s.d.	Shoots m^{-2}	s.d.
Phragmites communis	70.9	21.48	83.8	28.80
Scolochloa festucacea	3.7	12.0		
Carex atherodes	8.2	11.88		
Urtica dioica			2.3	4.52
Chenopodium rubrum	14.2	22.68	4.3	8.28
Lycopus asper	19.0	19.28	4.6	6.12
Mentha arvensis			4.8	5.44
Stachys palustris			13.1	9.56
Teucrium occidentale	6.4	9.8	11.2	11.84
Cirsium arvense			5.0	6.88
Sonchus arvensis			1.6	3.36

2. Plant Height

The average mature height of the *Phragmites* shoots at Site A and B and in the lysimeters are presented in Tables XXI and XXII. The difference between the mean plant heights in the two stands was not statistically significant in 1970, but there was a significant difference of 20.66 cm ($p < 0.005$) in 1971. The mean height of the *Phragmites* in the stands ranged from 167.8 cm to 193.68 cm. The height of the shoots in lysimeters 2A and 3B was similar to those in the stand because they were transplanted after the *Phragmites* had reached maturity (August 18). The height of the shoots growing in the other lysimeters was significantly ($p < 0.01$) less than the height of the plants in the stand, the difference being as much as 50 cm.

The soil monoliths for the lysimeters were obtained from regions of above average density to insure a representative volume of vegetation even if some of the plants were damaged. Observations made later in the season revealed that the shoots in such areas were shorter and had a lower leaf area than those in regions of average density. This difference which was not noticeable when the transplants were selected but became apparent later, contributed to the lower mean height of the lysimeter plants. In 1971 the shoots in the lysimeters had a similar height to those in the stand with the exception of lysimeter 1B. Even in 1B, there was one shoot with a maximum height of 211 cm and three others over 170 cm showing that it was the large number of abnormally small plants which reduced the mean.

TABLE XXI Mean mature height of *Phragmites* in the stands and in lysimeters in 1970

Site A			Site B		
Sample	Mean Height (cm)	s.d.	Sample	Mean Height (cm)	s.d.
Stand	186.40	24.25	Stand	193.68	30.83
2-A	169.42	32.6	1-B	145.71	35.94
3-A	147.05	39.66	3-B	185.00	45.24
4-A	136.81	29.85	4-B	162.56	37.72

TABLE XXII Mean mature height of *Phragmites* in the stands and in lysimeters in 1971

Site A			Site B		
Sample	Mean Height (cm)	s.d.	Sample	Mean Height (cm)	s.d.
Stand	167.80	37.76	Stand	188.46	30.54
2-A	185.56	24.73	1-B	146.00	34.14
3-A	161.00	37.82	3-B	175.61	25.41
4-A	174.00	32.3	4-B	178.29	19.76

3. Leaf Area

The performance of the shoots in the lysimeters and those in the stands was also compared on the basis of leaf areas (Tables XXIII and XXIV). The shoots in the stand at Site A had a lower leaf area than those at Site B; 310.3 to 321.2 cm^2/shoot at Site A and 378.8 to 421.0 cm^2/shoot at Site B, the difference being significant ($p < 0.01$) in both years. In 1970, the mean leaf area of *Phragmites* in the lysimeters was significantly lower than that of the shoots in the stands. In 1971, only lysimeter 1B had a mean leaf area significantly ($p < 0.01$) lower than the plants in the stand.

The total leaf area of each lysimeter and the leaf area of shoots occupying an equivalent area in the stand was measured (Figure 31a, b, c and d) to provide a comparison between the LA's in the lysimeters and in the stand at various times of the year, and also to depict the seasonal growth patterns. In 1970, shoot growth began on June 1 at Site A and May 30 at Site B and the leaf area curves are extrapolated to a zero value on those dates.

In 1970, the LA of lysimeter 4A was similar to the stand but was larger in lysimeters 2A and 3A. The actual leaf area of lysimeters 3A and 4A on August 11 was 25.4 dm^2 and 16.4 dm^2 respectively. The LA of the lysimeters and the stand at Site B was similar, being 24.4 dm^2 in lysimeter 1B, 19.6 dm^2 in 3B, 19.5 dm^2 in 4B compared to 21.3 dm^2 in the stand on July 25.

TABLE XXIII Mean leaf area per plant (cm^2) in the stands and the lysimeters in 1970, when the leaf area of the stand was at a maximum.

Site A			Site B		
Sample	Mean Leaf Area cm^2	s.d.	Sample	Mean Leaf Area cm^2	s.d.
Stand	321.15	110.57	Stand	421.00	123.49
2-A	291.56	138.02	1-B	154.78	83.84
3-A	236.83	109.32	3-B	302.2	195.78
4-A	223.65	128.66	4-B	201.24	95.67

TABLE XXIV Mean leaf area per plant (cm^2) in the stands and the lysimeters in 1971, when the leaf area of the stand was at a maximum.

Site A			Site B		
Sample	Mean Leaf Area cm^2	s.d.	Sample	Mean Leaf Area cm^2	s.d.
Stand	310.26	112.71	Stand	378.81	120.54
2-A	251.78	103.49	1-B	210.37	122.18
3-A	241.1	121.0	3-B	290.83	185.6
4-A	353.25	176.29	4-B	360.47	92.71

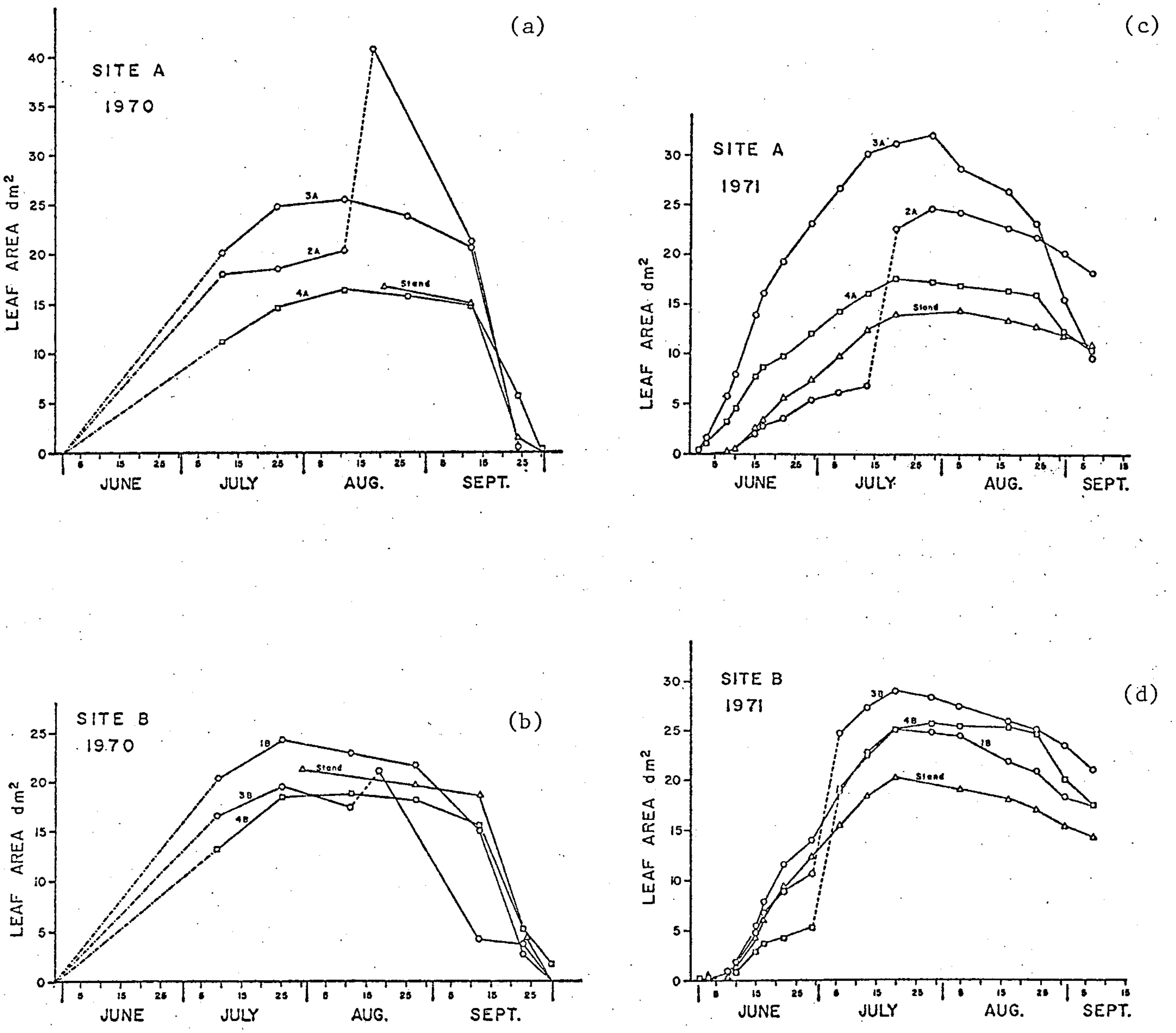

Figure 31 Total leaf area of *Phragmites* in the lysimeters and stand; (a) Site A, 1970, (b) Site B, 1970, (c) Site A, 1971, (d) Site B, 1971

In 1971, the leaf area of the lysimeters was higher than in the stand except in the lysimeters damaged by the *Apamea* larvae. At Site A, the leaf area of the stand was 14.0 dm^2 while lysimeter 3A had a leaf area of 31.3 dm^2 on July 20. On the same date, the leaf area of the stand at Site B was 20.3 dm^2 compared to a leaf area of 29.1 dm^2 in lysimeter 3B.

The decline in the leaf area after the midsummer peak, was caused by the senescence and abscission of the lower leaves. The sharp decline in the leaf area in the latter part of September 1970 was caused by a killing frost. The growth and senescence curves for the plants in the lysimeters and the stand were similar, indicating that normal plant growth was realized in the lysimeters.

In 1971, the leaf area index (LAI) of the *Phragmites* at Site A was lower than at B (Figure 32). The maximum LAI for Site A was 2.26 m^2m^{-2} on August 5 but since there was a time period of 16 days between the measurements on July 20 and August 5, the maximum may really have been higher. At Site B the maximum LAI, 3.17 m^2m^{-2} was observed on July 20.

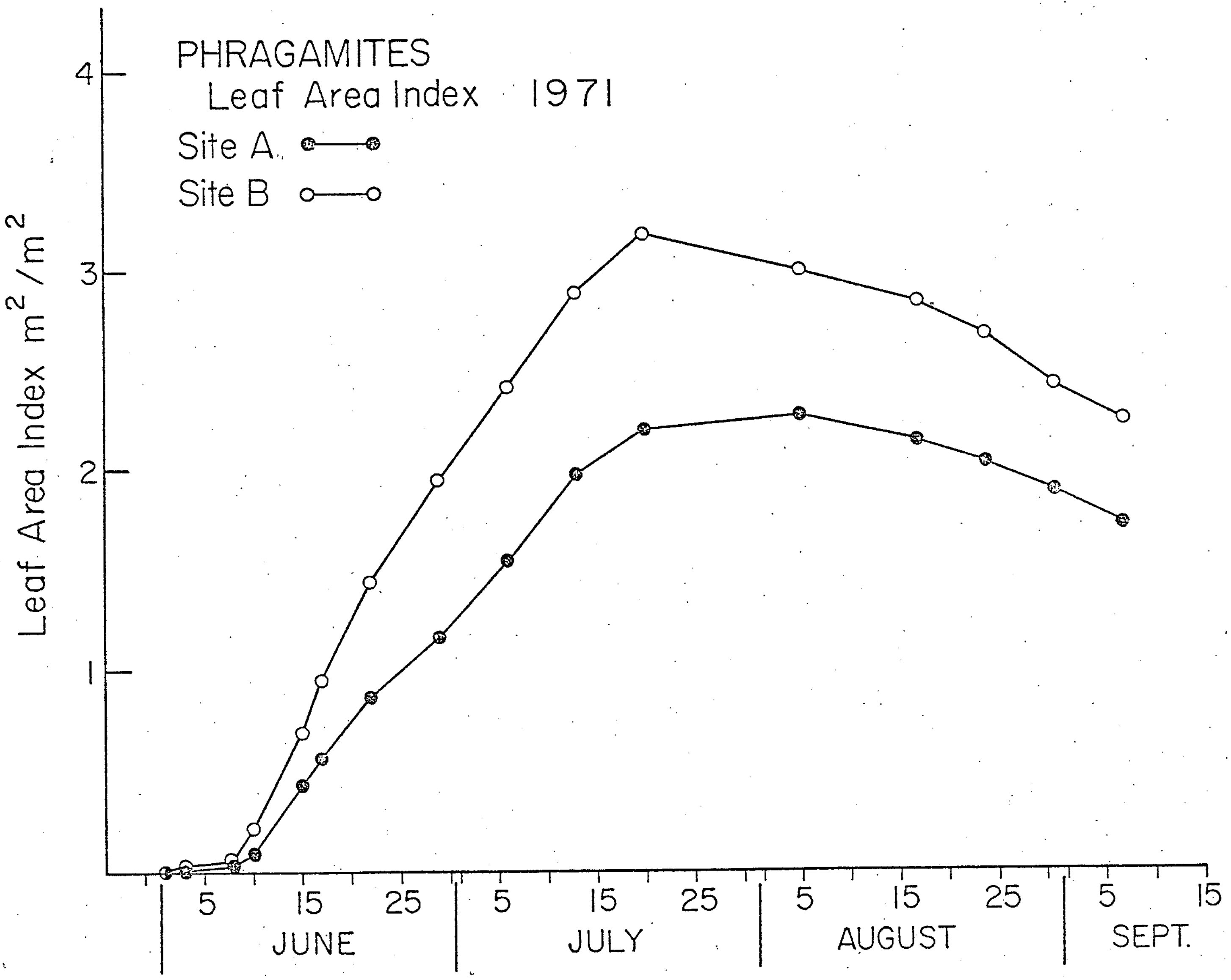

Figure 32 Leaf area index of *Phragmites* stands at Site A and B in 1971

CHAPTER IV

DISCUSSION

CHAPTER IV

DISCUSSION

A. Evapotranspiration

1. Lysimeter Measurement

In this study, the hydraulic load cell lysimeter was chosen because (i) the lysimeter size could be reduced [Courtin & Bliss, 1971] thus reducing damage to the stand, (ii) it was adaptable to wet conditions and (iii) the lysimeter did not have to be moved to take the readings. Floating lysimeters [King *et al.*, 1956] could not be used because they are typically large and the heavy equipment needed to install them would have caused excessive damage to the *Phragmites* stands. Mechanical weighing devices mounted below the lysimeter [Libby and Nixon, 1963] were unsuitable because of the wet conditions and beam balances [Wilcox, 1963] would have required a scaffold above the lysimeter and frequent lysimeter movement which could have broken the plants. The only problem with the hydrostatic system was temperature induced changes in the height of the water column in the standpipe and this was successfully overcome by using a control lysimeter.

If the results of an evapotranspiration experiment are to be applied to an undisturbed plant community the lysimeter must be representative of its surroundings. To be representative, a lysimeter must be indistinguishable from the rest of the stand, the plants in it must have the same height and density as the surrounding community, the non-cropped area around the installation must be small and moisture availability the same [King *et al.*, 1956].

In the present study, every possible precaution was taken to obtain a representative lysimeter exposure. The success which was achieved can be seen in Figure 13, p. 47. There was no disturbance on the east, west or south and to the north there was only a narrow foot-path. The total leaf area of the plants growing in each lysimeter was greater than for an equivalent area in the stand (Figure 31 a, b, c and d. These differences were not significant at Site B and Site A only lysimeters 2A and 3A had significantly higher ($p < 0.05$) leaf area than the stand. Because of the differences in the LAI of the lysimeters and stand, the unit leaf rate of transpiration was used to compute the daily transpiration of the stand. Gatewood *et al.* [1950] and Gel'bukh [1964] used similar methods in extrapolating transpiration rates from lysimeters to larger regions dominated by the same species.

In all but two of the lysimeters used in 1970, the *Phragmites* were not as tall as those in the stand (Table XXI),but in 1971 only lysimeter 1B had a lower mean shoot height than the stand (Table XXII), a factor which could have affected wind ventilation and light exposure.

Although the mean plant height was lower than in the stand, each lysimeter had at least three plants which were larger than average for the stand (180 to 190 cm). It is felt that this was a reasonable number of plants of comparable size since the mean number of shoots for this area in the stand was 5 with a range of 0 to 11. It was the frequency of small shoots which reduced the mean height and leaf area. The higher density of shoots in the lysimeters probably reduced the height of individuals because of intraspecific competition [Haslam, 1971]. This occurred because monoliths were taken from high density areas to allow for mortality and still insure the survival of 4 or 5 shoots. In addition, up to 3 new shoots, which were very small, emerged in each lysimeter after transplanting, a response that may have been initiated by cutting the rhizomes [Haslam, 1969].

In 1971, the mean plant height in the lysimeters was greater (Table XXII) than in the stands even though the density of *Phragmites* shoots was similar to that in 1970. Even the plants involved in the mid-season transplants into lysimeters 2A, 3B and 4B continued to grow as well as those in the stand. Thus, in the second year of the study, plant height in the lysimeters was representative of the stand.

The evaporation lysimeters had the same exposure as the others, the only difference being that green plants were not growing in them. Nevertheless, the soil was shaded by the surrounding *Phragmites* which tended to bend in over the installations. The soil surface in the evaporation lysimeters as well as the evapotranspiration lysimeters resembled that under the stand because the litter and dead stalks were left intact.

The moisture characteristics of the soil in the lysimeters at Site A was representative of the surroundings because the water table was maintained at the same depth. At Site B, this was not possible through the entire season because the water table fell below the maximum depth of the lysimeter. When this occurred, the water table was maintained at 2 to 3 cm from the bottom of the lysimeter. This was done because roots of *Phragmites* in the stand were found at depths of 80 to 90 cm and it was assumed that these roots would be in contact with the saturated zone of the soil at all times. An argument against maintaining a shallower water table was that it might increase the soil moisture in the surface zones. However, examination of the soil moisture profile (Table XV) obtained when the water table was at -105 cm indicated that there was no significant difference in the moisture percentage between the 21-40 cm samples and the 81-100 cm samples. Thus, the moisture regime was considered representative in all lysimeters.

In addition to leaf area, plant height, moisture conditions and exposure of the lysimeters, their thermal regime should also be representative. In the present study, the mean daily soil temperature in the lysimeter did not exceed that of the surrounding soil by more than 2.0 °C (Table VIII). Courtin and Bliss [1971] using smaller lysimeters (25 cm vs. 29 cm diam.) in a *Carex bigelowii* community found that temperatures at the -15 cm depth within the lysimeter exceeded those in the surrounding soil by about 2 °C. Black *et al.* [1968] using a large lysimeter (4 m diam.) found that the maximum daily temperature fluctuations in the lysimeter soil differed from that 5 m away by 1.2 °C. Higher soil temperature has been found to stimulate the transpiration rate, each 2 °C rise in temperature increasing T_R by about 5 percent [Cox and Boersma, 1967; Wallace, 1970]. Assuming that *Phragmites* responds similarly to the species used in these studies, a small increase in transpiration, as a result of higher lysimeter soil temperatures, probably occurred.

In view of the preceding discussion, it is evident that the lysimeters closely resemble the conditions in the surrounding stand and therefore were capable of yielding a representative estimate of actual evapotranspiration.

The sensitivity of the lysimeters was lower than for the larger type, 0.5 mm compared with 0.006 mm [King *et al.*, 1965], 0.08 mm [Black *et al.*, 1968], Courtin and Bliss [1971] using hydrostatic lysimeters also found that sensitivity was sacrificed as the size decreased. The sensitivity of their lysimeters was 0.25 mm. The lower sensitivity of the lysimeters in this study result from a reduced loading ratio, the ratio of lysimeter weight to the area of contact between the lysimeter and hydrostatic bolster. It could have been increased by using a smaller bolster such as a bicycle inner tube [Courtin and Bliss, 1971] but the heavier inner tube was favoured to reduce the drift in calibration resulting from stretching of the rubber. In any case, the lysimeter accuracy was adequate to describe evapotranspiration over 24 hour periods.

2. Evaporation, Transpiration and Evapotranspiration

Evaporation rates declined as the summer progressed, mainly because of the increased shading as the LAI of the stand increased. The increasing height and LAI contributed further to reduce the evaporation rate by decreasing the air movement at the soil surface. In the first 3 weeks of June, E may have been increased over the norm for the stand because of immature height the "stand" plants and their resultant inability to provide representative shade to the evaporation lysimeters.

Evaporation from the soil surface constituted a significant percentage of the total evapotranspirational loss. In mid-summer, evaporation was 20 to 25 percent of the total at Site A and 8 to 15 percent at Site B. This percentage is comparable to that of 20 percent for other *Phragmites* communities [Gel'bukh, 1964]. Crops grown on agricultural land where drier conditions prevail have an E percentage of 10 percent [Begg *et al.*, 1964].

Evaporation was generally less at Site B than at Site A. It is felt that the physical condition of the litter and the availability of moisture at the surface may have contributed to this difference. At Site A the litter was compacted because of flooding in May and early June. Litter of the soil surface decreases evaporation by increasing the length of the vapour pressure gradient between the soil and the air [Blevins *et al.*, 1971]. The moisture content at the soil surface was higher at Site A than Site B, 328 percent vs 88 percent (Table XV) determining factors being the higher water table and higher organic content of the soil (Table XVI).

The seasonal pattern in transpiration by *Phragmites* showed a steady increase until late July or early August followed by a gradual decline until the death of the plants in September. It appears from the meteorological data that this pattern existed because of changes in the evaporative potential, created by higher temperature and net radiation in conjunction with lower relative humidity in July and August. However, when one examines the unit leaf rate of transpiration, in July and August (Figure 30 a, b, c and d) a stable pattern emerges, suggesting that T_R at the community level was primarily dependent on LAI.

This view is supported by Shaw and Fritschen [1961], Graham and King [1961], Tanner and Lemon [1962] and Begg *et al.* [1964] who considered the direct effect of leaf area changes and the indirect effects of canopy development on meteorological parameters to be of primary importance in determining transpiration rates. In June, during the rapid growth phase of the plants, the unit leaf rate of transpiration decreased as the LAI was increasing. There is the suggestion here that T_R by younger leaves is higher than in older; later in the season this effect was not evident because of the averaging effect of the older, less active leaves. In September, the unit leaf rate increased as the LAI was declining due to senescence. This was probably related to the method of measuring the LAI in that only green non-chlorotic leaf material was considered. However, there were chlorotic leaves on the plants which were not wilted and may still have been capable of active transpiration. This would have the effect of increasing the unit leaf rate of transpiration for the non-chlorotic leaf area. Other studies have found increased transpiration per unit leaf area in the spring and autumn [Gel'bukh, 1964; Imhof and Burian, 1972]. It appears that the first two or three leaves on the plants have a high capacity for transpiration which may be related to the physiological age of the leaves [Królikowska, 1971]. The effect may also be partially physical in that as the number of leaves increase, shading of the lower leaves occurs and the available radiant energy is distributed to more leaf tissue. Development of the canopy also reduces the wind ventilation allowing a thicker vapour blanket to form around the lower leaves thus reducing their transpiration potential [Begg *et al.*, 1964]. Because the total leaf area of the plants was used in calculating the transpiration the net result would be to lower the rate per unit leaf area.

There is some controversy about whether the physiological age of the plants has a significant effect on transpiration capacity. Gel'bukh [1964] emphasized the effect of physiological age of the transpiration rates in *Phragmites*. Denmead and Shaw [1959] felt that in corn the transpiration rate decreased after the commencement of ear growth because of declining physiological activity. Others consider the direct effect of leaf area changes and the indirect effects of canopy development on meteorological parameters to be more important in determining transpiration rates [Shaw and Fritschen, 1961; Graham and King, 1961; Tanner and Lemon, 1962; and Begg *et al.*, 1964]. I feel that the physiological age of the leaves may exert a dominant influence of T_R early in the season when LAI is small but the LAI and canopy development later become the dominant factors.

The transpiration rate was lower at Site A than at Site B in terms of both rate per unit leaf area (ml dm^{-2}) and total daily T_R. Because of the lower LAI at Site A it may have intercepted less radiation within the canopy hence reducing the energy available to drive the vaporization process. On the other hand, Kiendl [1953] found that denser stands had a lower transpiration per unit weight but a greater total loss of water. Gel'bukh [1964] also found that the unit leaf rate of transpiration was greater in the stands with the lower LAI and reasoned that they were more accessible to solar radiation and had better wind ventilation. Although stands with lower LAI's are more accessible to net radiation it does not necessarily follow that a larger amount is intercepted within the canopy. The efficiency of use of the incoming radiation should be greater in denser canopies because the reflected and reradiated energy has a higher probability of being intercepted by other leaves. As for differences in ventilation, wind did not affect the rate of evapotranspiration (cf. multiple linear regression, p. 141) in the present study. Thus, the lower LAI index could not have affected transpiration through its effect on wind ventilation.

The seasonal pattern in evapotranspiration was very similar to that for transpiration; an expected result considering that transpiration contributed 75 percent to 90 percent of the total water loss. Daily transpiration and evapotranspiration rates were not always closely matched between the two sites, but the three lysimeters at each site responded similarly on a daily basis suggesting that site differences may have caused the variation in rates for a particular day. There was no way of achieving an identical microclimate at each installation and differences could have occurred because of this.

Gel'bukh [1964] and Fulton and Findlay [1966] found similar scatter in the values recorded by individual lysimeters.

Transpiration and evapotranspiration in 1970 was significantly higher than in 1971 but no significant differences in the environmental parameters could be detected. A similar case was noted in a six year study of evapotranspiration in a Papyrus swamp when shortly after transplanting, evapotranspiration was 6.0 mm day^{-1} [Migahid cited by Penman, 1963] but after six years it was only 3.4 mm day^{-1} [Migahid cited by Rijks, 1969]. This led to the hypothesis that transpiration rates may decrease with time after transplanting. However in the present study, this was not the cause of the reduced rate in 1971 since transplants were also made in that year to replace the lysimeters damaged by the *Apamea* larvae. On the other hand, the disturbance caused by the installation of the outside containers in 1970, minimal as it was, may have had an effect on the microclimate, letting more light through the canopy, increasing wind ventilation and creating unrepresentative temperature and humidity profiles. In 1971, there was no disturbance from installation activities and the microclimate of the lysimeters could have been more representative of the stand.

One other factor which could have reduced transpiration rates was the different ionic potential of the water in the soil. In 1970, there was no provision to drain the lysimeters to prevent the accumulation of minerals, so rain water (low mineral content) was added to maintain the water table. In 1971, the water was drained from the lysimeters on a weekly basis and replaced with fresh marsh water [1580 ppm, total dissolved solids, Gilliland, 1965]. The soil solution available to the plants in 1971, may have had a much higher ionic potential than that in 1970 and this could have affected the rate of absorption. The author discounts this hypothesis, because the transpiration/evapotranspiration ratio is the same for both years, and this could only occur if evaporation was reduced by the same factor as transpiration. The ionic potential of the soil would have a greater effect on transpiration than evaporation.

The evapotranspiration rate of *Phragmites* showed a seasonal maximum in July (Tables XVII and XVIII). The means for July 1970 (5.0 and 5.3 mm day^{-1} for Sites A and B respectively) may not be representative of actual rates through the whole month because they were computed from only three days of data. In 1971, the average rate in July was 3.6 mm day^{-1} for both sites. Gel'bukh [1964] reported that evapotranspiration from *Phragmites* was highest in July, when 211 mm of water was used, or an average rate of 6.8 mm day^{-1}. However, the LAI of the lysimeters was lower than in the surrounding stand. If this caused an increase in T_R per unit leaf area, the stand. If estimate based on relatives LAI's (lysimeter vs stand) would be exaggerated. The actual evapotranspiration from his lysimeters, 5.0 and 4.8 mm day^{-1} may be more realistic.

Rudescu *et al.* [1965] found that evapotranspiration rates were highest in August. The highest rates were recorded in the first year of his study, total evapotranspiration being 21.8 for August 1951; an average daily rate of 7.0 mm day^{-1}. In 1952, the total evapotranspiration in August was 14.9 cm or 4.9 mm day^{-1}. The mean daily consumption of the study period was 6.09 mm day^{-1} [Rudescu, *et al.*, 1965]. Haslam [1970] reported evapotranspiration from reed beds of 1-1.5 m annually. No monthly breakdown of this total was presented but the high annual total probably represents a long growing season with measureable evaporation or evapotranspiration in every month of the year. Królikowska [1971] reported that reed beds normally transpire 22.3 t ha^{-1} day^{-1} or 2.23 mm day^{-1} as a seasonal mean, highest rates being recorded from July 20 to July 31. Burian [1971] studied transpiration from a *Phragmites* community, with density 75 shoots m^{-2} and LAI 5 m^{2}m^{-2}, finding it to be 100 cm in 190 days or 5.3 mm day^{-1}. The highest mean daily rate, 10 mm day^{-1}, occurred in July. Preliminary measurements of transpiration from a wet and a dry site indicated comparative values in July of 6.88 and 11.37 mm day^{-1} respectively [Rychnovská and Śmid, 1973]. The lower rate at the wet site resulted in part from a lower LAI, 3.4 compared with 4.7 for the drier site. In conclusion, the average evapotranspiration by *Phragmites* in the present study was generally lower than that determined in Eurasia. The differences are probably attributable to different meteorological conditions and generally lower LAI.

The evapotranspiration rate of *Phragmites* was considerably less than for tules (*Scirpus* spp) which were estimated to use between 4.5 and 5.8 feet annually [Blaney, 1956]. The figures just quoted are means of several years (1921-1952) of evaporimeter records and some of the estimates may not have been representative of actual E_T because of poor exposure of the tanks [Young and Blaney, 1942].

In domestic rice, Evans [1971] observed high evapotranspiration rates often exceeding 10 mm day^{-1} and only one day in 25 had a rate less than 6.0 mm day^{-1}. This however, was a special case since the sites were highly advective, making more energy available for the vaporization process.

Evapotranspiration by agricultural crops has an extensive literature but cannot be compared with *Phragmites* because the crops were grown on drier sites and did not have similar canopy characteristics (height and LAI).

Even though evapotranspiration rates are lower than in other studies, the author feels that the agreement in the T_R/E_T ratios with that found by others supports the validity of this data. In 1971, transpiration accounted for 74 percent to 90 percent of evapotranspiration, Site B (drier) having the higher percentage (Tables XVII and XVIII). These figures are consistent with reports of 80 percent in a *Phragmites* stand flooded with water [Gel'bukh, 1963] and 90 percent in a bulrush millet stand with a LAI of 5 [Begg *et al.*, 1964]. In an alpine *Carex* community transpiration accounted for 93.4 percent of total evapotranspiration [Courtin, 1968].

B. Shallow Ground Water Table Fluctuations

1. Methods of Analysis

In the analysis of water table fluctuations, there are two methods to consider that of White [1932] and Troxell [1936]. Both use approximations of the recharge rate and derive an evapotranspiration estimate by measuring the net change in the water table with time and estimating the amount of recharge over the same time. In the White formula [White, 1932], the recharge rate is assumed to be the same through the day and recharge over each 24 hour period is added to the net drop in the water table to estimate the evapotranspiration (E_{WT}). Troxell [1936] derived a more sophisticated analysis by integrating the water table fluctuation at hourly intervals. Allowances are made for the fact that the rate of recharge is not constant but varies according to the static head operating on the ground water flow system. The rate of recharge is highest in the late afternoon because the static head is greatest when a cone of depression develops beneath the rapidly transpiring plant community. On the other hand, the rate of recharge is lowest in the early morning when the water table reaches its maximum daily height and the static head is small.

The evapotranspiration estimate is obtained by integrating the difference between the recharge curve and the drawdown curve for each hour of the day. Although the analysis requires some approximation in drawing the curve representing the recharge rate, it does have the potential for providing a more accurate estimate of the water withdrawn for evapotranspiration. The "Troxell Analysis" was tested against the White formula estimate for three typical days showing high evapotranspiration rates. The Troxell method gave a slightly higher evapotranspiration estimate but the results did not differ enough to justify the additional analysis time. Meyboom [1967] arrived at a similar conclusion when he compared the two methods and the application of White's formula to water table records beneath phreatophytic communities yielded evapotranspiration estimates which agreed well with expected values. The White formula was used to quantify the water table fluctuations recorded in the present study.

2. Estimates of Evapotranspiration from Water Table Fluctuations

In estimating consumptive use (E_{WT}) of *Phragmites* by analyzing the water table fluctuations, it became evident that when the water table was near the surface, E_{WT} increased as the water table decreased (Figure 24a, b, c and d). At Site A, this direct relationship held true until the water table reached a depth of -40 cm after which an inverse relationship was noted [Robinson,1958; Blaney,1954; Ward,1963; Meyboom, 1967; Jackson, 1973]. At Site B, the direct relationship between water table depth and E_{WT} was observed until the water table had dropped to -40 to -50 cm but when depths of 90 to 100 cm were reached, less than 2 mm H_2O day^{-1} was being withdrawn from the saturated zone.

It is believed that the direct relationship observed in the present study was related to the porosity and readily available specific yield of the soil at different depths [Ward, 1963]. The upper 20 cm zone had a higher sand content (Figure 25) and organic percentage (Table XVI) than the deeper zones while the physical characteristics of the 21-40 cm zone were intermediate. Therefore, porosity and specific yield (water) would be greatest at the surface but would decrease with depth.

Reasons for the inverse relationship between depth to the water table and E_{WT} below 90 cm at Site B are only speculative. One ex- explanation is that evaporation from the soil surface plays a significant role in the daytime drop in the water table and as the depth increases, vertical transport for that use is reduced [Meyboom, 1967]. Evaporation data collected in the present study agree with other reports [Gel'bukh, 1963; Begg *et al.*, 1964] that the evaporation from the soil surface usually does not exceed 25 percent of the total water use. Complete cessation of this loss would only decrease E_{WT} by a factor of 25 percent. However, E_{WT} was reduced by more than 50 percent based on maximum and minimum values (Figure 24 b and d) and therefore some other explanation must be sought.

Another possibility is that absorption by the roots may decrease as the depth to the water table increases [Jackson *et al.*,1973]. That the density of roots was observed to decrease with increasing distance below the rhizomes supports this hypothesis. No information is available to prove or disprove it because the inverse relationship between E_{WT} and water table depth occurred when the water table was below the depth of soil in the lysimeters.

No relationship was readily detectable between E_{WT} and E_T (Figure 33 is an example scattergram of all available data, Site B, 1971). At Site A the lack of agreement can be associated with the changing soil characteristics mentioned above and their effect on specific yield. The water table did not drop lower than -40 cm and uniformity of the soil particle size distribution and the organic content only occurred below -40 cm. It was

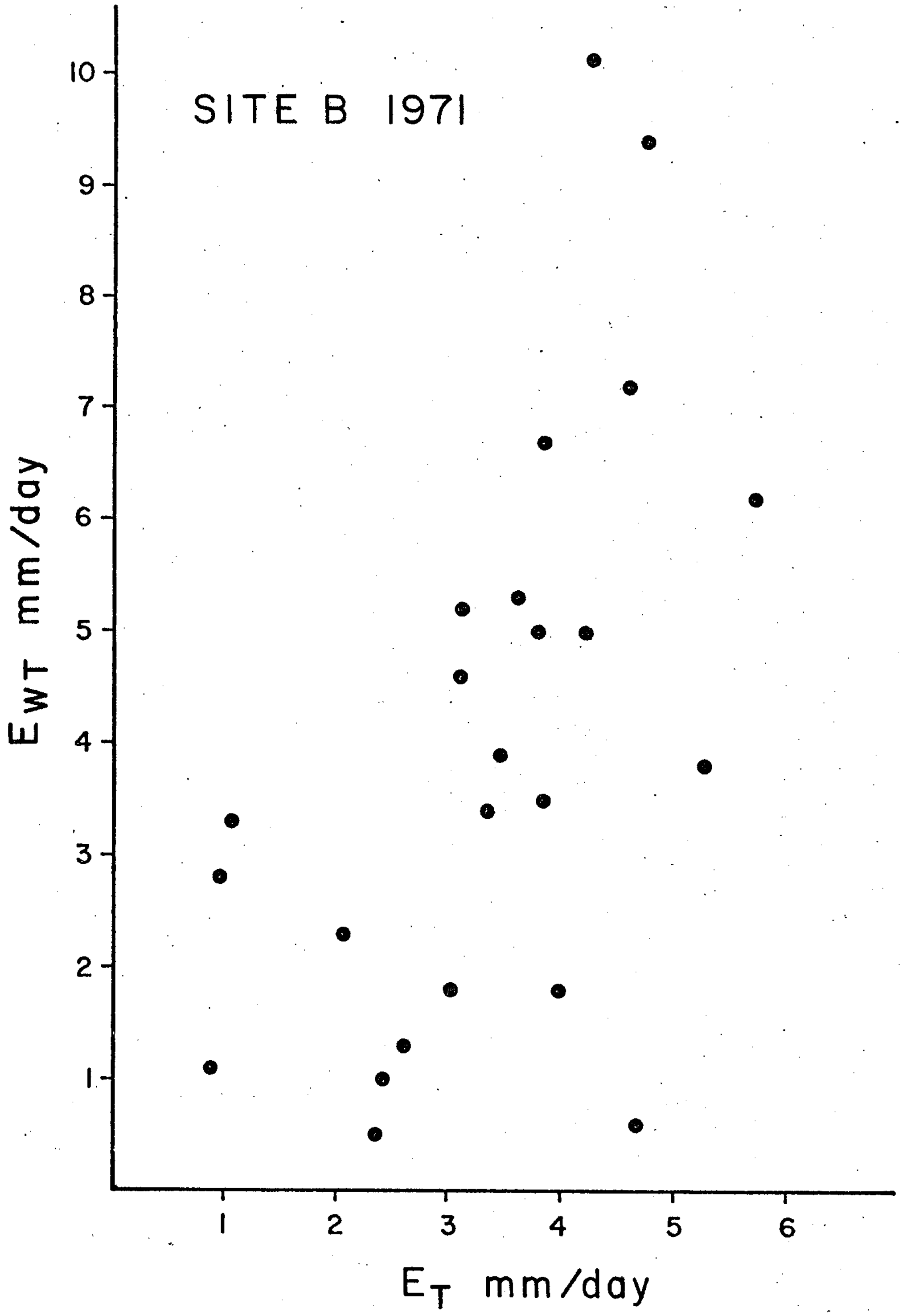

Figure 33 Scattergram showing the lack of agreement between an evapotranspiration estimate based on water table fluctuations (E_{WT}) and evapotranspiration measured with lysimeters (E_T), site B, 1971 when all available data are used.

expected that E_{WT} would be correlated with E_T at Site B because the water table fluctuated to -100 cm and particle size and organic content were fairly uniform below -20 cm. Thus, the lack of agreement must be attributed to the fact that other natural processes besides evapotranspiration affect the magnitude of the water table fluctuations and hence the E_{WT} estimate.

One such factor was rainfall, even small amounts of rain cause the water table to rise markedly, e.g. 18.3 cm rise per 1.0 cm of rain [Meyboom, 1967, p. 14]. The infiltrated rain "seals" the soil surface and compresses the air above the capillary fringe. The pressure displaces the capillary fringe downward, increasing the water in the saturated zone by an amount equal to the volume of water forced out of the capillary zone [Meyboom, 1967]. Recovery occurs when the infiltrated rain is dissipated by seepage, a process which may take up to 10 days.

Another effect occurs when rainfall percolates down to the water table. This causes the water table to rise because of direct additions to the saturated zone. Stabilization of the water table after such an event involves a return of the soil, above the water table, to field capacity by the gravitational movement of water. Such downward percolation may require a number of days, during which time water is being added to the saturated zone [Linsley *et al.*, 1949, p. 409]. Because of the Lisse effect and the unpredictable rate of percolation recharge E_{WT} may bear no evident relationship to evapotranspiration for a period of up to 10 days after a rain [Meyboom, 1967].

Examination of E_{WT} through each season, (Figure 24 a to d shows that there was an increase until midsummer and then a decrease in the fall. Because of the frequency of rainfall, it is felt that most of the estimates are not valid but there is an indication that the evapotranspiration rate was affecting the magnitude of the diurnal fluctuations. For example, when the water table rose to the same level in September (10 to 13) as it was in early August (24-30) (Figure 24c), E_{WT} was 25 percent lower than it had been earlier. Support for the idea that other factors such as rainfall and water table depth influenced E_{WT} is also evident when one compares the peak at the two sites. Even though they were both influenced by the same weather conditions, the peak in E_{WT} occurred approximately 2 weeks earlier at Site B.

3. Relationship Between Evapotranspiration and Water Table Fluctuations

Precipitation was a frequent occurrence during both summers of this study (Figure 23 a and b) and only in August 1970 were there enough rain free days to test the relationship between water table fluctuations and evapotranspiration. A correlation between the two parameters was sought for two periods, August 5 to 13 and August 20 to 27 (Figures 34 a and b). The final rainfall event in July occurred on July 24, thus, August 5 was chosen as a starting date for the correlation scattergrams because it allowed 12 days for stabilization of the water table. No rain was recorded until August 14 and then only a trace.

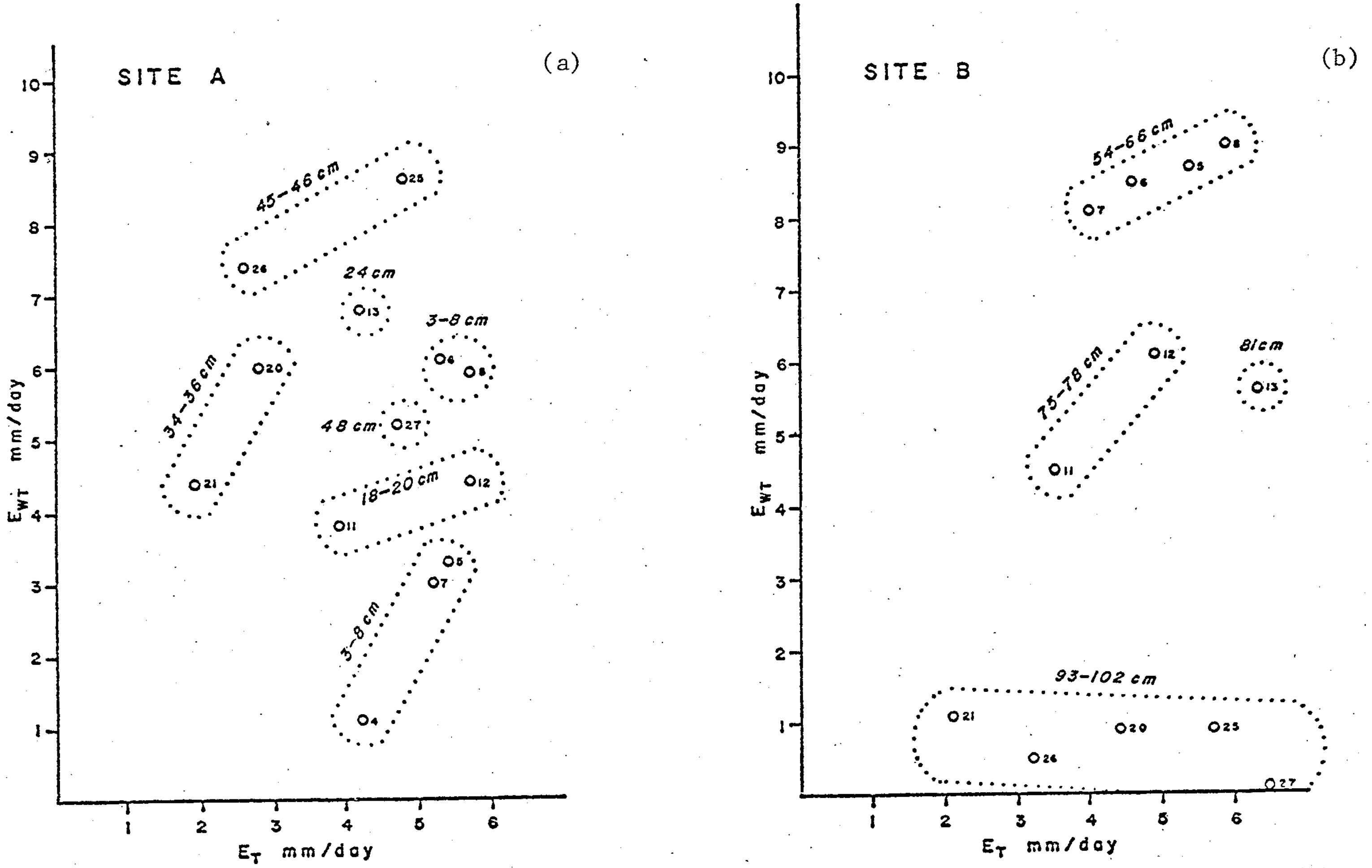

Figure 34 Relationship between E_{WT} and E_T during a dry period in August 1970; (a) Site A, (b) Site B. Small numbers to the right of the points correspond with the date in August on which the data were collected. Points within a finite range of water table depths are encircled to show the effect of water table depth on the relationship

On the scattergrams, dates are indicated for each point and those within a finite range of water table depths are encircled to show the effect of water table depth on the relationship. In spite of the many factors which could modify water table fluctuations, the direct relationships which exist between evapotranspiration and E_{WT} suggest that withdrawal of water from the saturated zone of the soil to satisfy the E_T demand, was causing the duirnal fluctuations. This only becomes evident when points of similar water table depth are delineated. Unfortunately, the role of depth in the relationship makes it impossible to establish a quantitative relationship.

No relationship existed between evapotranspiration and E_{WT} at Site B (Figure 34b when the water table was in the 93 to 102 cm range. The *Phragmites* roots may not have been in direct contact with the saturated zone of the soil at that depth in which case the water for evapotranspiration must have been absorbed from shallower soil zones. Living roots were observed at a depth of 100 cm but the number encountered in the 80-100 cm zone was few. Either these roots were not absorbing a significant amount of the plants water requirement or some hydrological phenomenon was inhibiting the expression of the withdrawal. The latter hypothesis would necessitate the existence of a factor (such as increased sand content) which could increase the porosity and hence specific yield and/or recharge rate in this zone. Sand lenses were found when the observation well was drilled at Site B but none were encountered in the soil samples (Figure 25). It is the writer's opinion that the sand lenses encountered in the observation well may have affected the magnitude of the duirnal fluctuations. It is also felt that decreased absorption rates in this zone may have contributed to the observed damping of the fluctuations.

C. Meteorological Parameters

1. Meteorological Data

Of the meteorological parameters which affect the evapotranspiration rate, radiation is considered to be the most important [Graham and King, 1961; Tanner and Lemon, 1962; Davenport, 1967; Lemon *et al.*, 1971]. Net radiation gives a measure of the energy available for the vaporization process after reflection and reradiation losses and is usually the climatic variable most closely correlated with evapotranspiration [Tanner and Pelton, 1960]. In this study there was a strong positive correlation between R_N and R_I (Figure 18), indicating that short-wave radiation provided a satisfactory measure of available energy. Consequently, correlations between evapotranspiration and short-wave radiation should be as strong as those using net radiation.

Mean daytime air temperatures were slightly lower at Site B (Tables III & IV) which may have been related to higher rate of evapotranspiration. Temperatures within the *Phragmites* canopy were similar to those above it (Tables V and VI) indicating the little energy was being drawn from the overlying air mass. The mean temperature depression of 3.3°C near the top of the stand at Site B in August (Table VI and Figure 20b), suggests that a temperature sink was created near the top of the canopy by rapid transpiration. It is not known why a similar temperature profile did not develop in July. Transpiration rates, radiation, relative humidity and temperature were all similar for the two periods and the temperature profile should also have been similar.

A comparison of the temperature profiles at the two sites (Figures 20 a and b) shows that the wetter soil surface at Site A was a more effective energy sink than that at Site B. This, together with the greater availability of moisture, may have been the reason for the higher evaporation rate at Site A.

The mean daytime wind speed at the two sites was not significantly different (Tables IX and X) in either year although two different models of anemometer were used in 1970. In pre-season tests, the Casella, used at Site A had a slightly higher (n.s.) integrated output than the Thornthwaite from Site B, its larger mass apparently causing it to "coast" longer after a wind gust. Wind movement within the *Phragmites* stands was minimal, these anemometers being unable to detect it.

Relative humidity appeared to be slightly lower at Site A although differences were not significant (Tables XI and XII). Considering the ±5 percent error in the response of the hygrographs, psychrometric readings would have represented the vapor in the air more precisely. However, in the absence of continuously recording psychrometers, it was felt that the hygrograph record provided a much better representation of the daily vapor content of the air than once or twice daily pyschrometer readings.

Precipitation affected the data in two ways. In the first place, it precluded the demonstration of significant correlations between E_{WT} and evapotranspiration by *Phragmites* (see p. 131). Precipitation also limited the collection of evapotranspiration data to non-rainy days. On the other hand, the seasonal rainfall totals (Table XIII) were of particular significance in computing a seasonal water budget for the marsh. Although an attempt was made to collect data on the interception of rainfall using a profile of rain gauges through the *Phragmites* canopy, only trace amounts were recorded at the soil surface and it became obvious that rain was being intercepted by the *Phragmites* leaves and transmitted via stemflow to the ground. Consequently, no estimates of the interception losses were forthcoming.

2. Relationship Between Meteorological Parameters and Evapotranspiration

The simple correlation coefficients between each of the environmental parameters and evapotranspiration are presented in Table XXV. There was a highly significant correlation ($p < 0.01$) between evapotranspiration (E_T) and both radiation parameters. Net radiation (R_N) accounted for 72 percent (R^2) of the variation in evapotranspiration at Site A in 1971 and 55 percent at Site B. A slightly better correlation with E_T was obtained using R_N rather than incoming short-wave radiation.

The correlations between E_T by *Phragmites* and R_I or R_N are similar to reports for other species. In relating R_I to E_T by alfalfa

KEY:

E_T - daily evapotranspiration (mm H_2O per day)

R_I - incoming short-wave radiation (mm H_2O equivalent per day)

R_N - daytime net radiation (mm H_2O equivalent per day)

T - average daytime air temperature (^oC)

W - average daytime wind speed (meters per second)

RH - average daytime relative humidity (%)

TABLE XXV Simple correlation coefficients of evapotranspiration on the meteorological parameters

		Parameters		Correlation Coefficients	
Site	Year	y	x_i	Simple	Sig. (p <)
A	1970	E_T	R_I	0.78	0.01
B	1970	E_T	R_I	0.77	0.01
A	1971	E_T	R_I	0.84	0.01
B	1971	E_T	R_I	0.72	0.01
A	1971	E_T	R_N	0.85	0.01
B	1971	E_T	R_N	0.74	0.01
A	1970	E_T	T	0.71	0.01
B	1970	E_T	T	0.55	0.01
A	1971	E_T	T	0.32	N.S.
B	1971	E_T	T	0.43	N.S.
A	1970	E_T	W	-0.3	N.S.
B	1970	E_T	W	0.03	N.S.
A	1971	E_T	W	0.36	N.S.
B	1971	E_T	W	0.05	N.S.
A	1970	E_T	RH	-0.54	0.01
B	1970	E_T	RH	-0.60	0.01
A	1971	E_T	RH	-0.74	0.01
B	1971	E_T	RH	-0.74	0.01

(*Medicago* spp.), clover (*Trifolium* spp.) and bromegrass (*Bromus* spp) Wilcox [1963] obtained a correlation coefficient of 0.67. Davenport [1967] reported a similar coefficient, r = 0.62, for the correlation between R_I and E_T from creeping red fescue (*Festuca rubra*). Net ratiation and evapotranspiration have been highly correlated r = 0.94 in a mixed alfalfa/brome stand (*Medicago* spp; *Bromus* spp) [Tanner and Pelton, 1960] and r = 0.988 in corn (*Zea mays*)[Graham and King, 1961]. At a highly advective site evapotranspiration from domestic rice (*Oryza sativa*) was poorly correlated with R_N (r = 0.51) because of the significant input of energy from air heated over adjacent regions [Evans, 1971].

Temperature was significantly correlated with E_T in 1970 r = 0.71 at Site A and 0.55 at Site B. There was no significant relationship between temperature and E_T in 1971. The reason for the discrepancy between the two years is not known. Other studies found a strong correlation between temperature and evapotranspiration [Wilxox, 1963; Hobbs and Krogman, 1966; Evans, 1971]. Davenport [1967] obtained a significant but low correlation (r = 0.52) between temperature and evapotranspiration but felt that the daily transpiration measurements were in error because of the slow response of his drainage type lysimeters.

Simple correlations between wind and evapotranspiration were not significant and this is in agreement with the findings of Kucera [1954], Wilcox [1963], Hobbs and Krogman [1966] and Davenport [1967]. On the other hand, Evans [1971] found a significant correlation, r = 0.48 between daily wind run and evapotranspiration. In that case, evapotranspiration was strongly influenced by temperature, the air being heated over adjacent dry areas and wind becoming an important agent in moving the warmer air into the experimental area.

Average daily relative humidity produced highly significant correlations with evapotranspiration in this study. Other studies reporting simple correlation coefficients for meteorological parameters, also found the vapor content of the air to be important to E_T [Wilcox, 1963; Gel'bukh, 1964; Hobbs and Krogman, 1966; Davenport, 1967].

It is evident from this discussion that the importance of any one meteorological parameter may differ according to the climatological conditions of the study. Evapotranspiration is generally highly dependent on the available radiant energy [Graham and King, 1961]. On the other hand, where advected energy was available to the site, temperature became a more important factor [Wilcox, 1963 and Evans, 1971].

The simple correlations discussed above merely assess the effects of each meterological parameter as a component of all the factors affecting evapotranspiration. Partial correlation coefficients, computed from a multiple regression analysis, are necessary to assess the true importance of each parameter when the others are held constant [Davenport, 1967].

Although the correlation coefficients for the multiple regressions of this study were highly significant (Table XXVI), certain regression coefficients were not significant (Table XXVII). For instance, average daytime temperature and average daytime wind speed in combination with the other meteorological parameters did not significantly affect the evapotranspiration rate. In most other studies, the correlation coefficient for temperature was significant [Wilcox, 1963; Hobbs and Krogman, 1966; Davenport, 1967; and Evans, 1971]. Temperature may not have shown its effect because of its dependence on solar radiation and when both factors were included in

TABLE XXVI Multiple linear regressions of daily evapotranspiration on meteorological parameters

		Equation												
Site	Year	y	=	a	+	b_1x_1	+	b_2x_2	+	b_3x_3	+	b_4x_4	r	Sig. p <
A	1970	E_T	=	-2.31	+	0.37 R_I	+	0.09 T	+	0.30 W	+	0.01 RH	.80	0.01
B	1970	E_T	=	0.95	+	0.53 R_I	-	0.004 T	+	0.49 W	-	0.02 RH	.82	0.01
A	1971	E_T	=	4.24	+	0.28 R_I	-	0.04 T	+	0.06 W	-	0.04 RH	.89	0.01
B	1971	E_T	=	6.48	+	0.13 R_I	+	0.04 T	-	0.41 W	-	0.06 RH	.86	0.01
A	1971	E_T	=	2.75	+	0.54 R_N	-	0.02 T	+	0.23 W	-	0.04 RH	.91	0.01
B	1971	E_T	=	5.72	+	0.26 R_N	+	0.05 T	-	0.34 W	-	0.06 RH	.87	0.01

KEY : E_T - daily evapotranspiration (mm H_2O per day)

R_I - incoming short-wave radiation (mm H_2O equivalent per day)

R_N - daytime net radiation (mm H_2O equivalent per day)

T - average daytime air temperature (°C)

W - average daytime wind speed (meters per second)

RH - average daytime relative humidity (%)

TABLE XXVII Significance of multiple regression coefficients

		Parameters		Multiple Regression Coefficients		
Site	Year	y	x_i	Partial	S.B.	Sig. (p<)
A	1970	E_T	R_I	0.37	0.19	0.05
B	1970	E_T	R_I	0.53	0.18	0.005
A	1971	E_T	R_I	0.28	0.07	0.005
B	1971	E_T	R_I	0.13	0.07	0.05
A	1971	E_T	R_N	0.54	0.12	0.001
B	1971	E_T	R_N	0.26	0.12	0.025
A	1970	E_T	T	0.09	0.07	N.S.
B	1970	E_T	T	-0.004	0.08	N.S.
A	1971	E_T	T	-0.04	0.08	N.S.
B	1971	E_T	T	0.04	0.1	N.S.
A	1971	E_T	T*	-0.02	0.08	N.S.
B	1971	E_T	T*	0.05	0.10	N.S.
A	1970	E_T	W	0.30	0.47	N.S.
B	1970	E_T	W	0.49	0.49	N.S.
A	1971	E_T	W	0.06	0.25	N.S.
B	1971	E_T	W	-0.41	0.25	0.1
A	1971	E_T	W*	0.23	0.22	N.S.
B	1971	E_T	W*	-0.34	0.24	0.1

...continued

TABLE XXVII (continued)

		Parameters		Multiple Regression Coefficients		
Site	Year	y	x_1	Partial	S.B.	Sig. (p<)
A	1970	E_T	RH	0.01	0.03	N.S.
B	1970	E_T	RH	-0.02	0.03	N.S.
A	1971	E_T	RH	-0.04	0.02	0.025
B	1971	E_T	RH	-0.06	0.02	0.005
A	1971	E_T	RH*	-0.04	0.02	0.025
B	1971	E_T	RH*	-0.06	0.02	0.005

* R_N replaced R_I in the analysis

<u>KEY</u> : E_T - daily evapotranspiration (mm H_2O per day)

R_I - incoming short-wave radiation (mm H_2O equivalent per day)

R_N - daytime net radiation (mm H_2O equivalent per day)

T - average daytime air temperature (^{o}C)

W - average daytime wind speed (meters per second)

RH - average daytime relative humidity (%)

the multiple regression, solar radiation dominated [Davenport, 1967]. This suggests that the energy for evapotranspiration in *Phragmites* came primarily from solar radiation.

It is possible that wind speed did not have a significant effect on evapotranspiration because it had little effect on air movement within the canopy. Observations during high winds indicated that the *Phragmites* flexed with the force of the wind seeming to close the canopy to the effect of the wind. The wind speed within the stands was less than 0.09 m sec^{-1} because anemometers with that starting speed were unresponsive. Furthermore, it has been suggested that wind is not a significant factor in determining evapotranspiration rates in humid regions, because of the absence of advective heat transfer [Tanner, 1960]. Wind appears to be important to evapotranspiration from advective sites mainly because it is the medium that moves the warmed air to the site [Hobbs and Krogman, 1966 and Evans, 1971].

The regression coefficients for relative humidity were significant in 1971 but not in 1970. This is consistent with the fact that simple correlations between relative humidity and evapotranspiration were not as strong in 1970 as in 1971 (Table XXV). There is no plausible explanation for this discrepancy.

There is also disagreement in the literature on the importance of vapor content to the evapotranspiration rate. Wilcox [1963] found that it was not significant in some of his data but significant in other portions. In a study by Hobbs and Krogman [1966], relative humidity did not correlate with E_T but vapor pressure deficit did, while Davenport [1967] did not find a correlation with vapour pressure deficit.

There are numerous multiple regression equations which relate evapotranspiration to meteorological parameters, and each places different emphasis on the individual factors. This is because each was developed under a unique set of environmental conditions. For this reason, it is not advisable to use a relationship developed elsewhere under different meteorological conditions. Of the equations developed from this study the use of those from 1971 is suggested because the exposure of the lysimeters was slightly better in that year. Furthermore, the equations should only be applied to *Phragmites* communities within the Delta Marsh which resemble Site A or Site B as to density, height, LAI and water table depth.

D. Water Balance in the Marsh

Total evapotranspiration by *Phragmites* between June 1 and September 10 was calculated from the monthly average E_T for the 1971 season, amounting to 30.8 cm at Site A and 30.5 cm at Site B. Total precipitation for the same period was 24.4 cm. The effective precipitation is usually less than the total because of interception losses, defined as the portion of precipitation that does not reach the soil but evaporates directly from the vegetation [Gray,1970,p.4.1]. It is dependent on a number of factors such as leaf surface morphology, angle of inclination of the leaves, LAI of the plant community and intensity and duration of the rain.

Of the species for which interception losses have been determined, wheat has a similar leaf arrangement to *Phragmites*, although its LAI may be lower. The interception loss from a crop of wheat during a 1.2 cm rainfall was 46 percent while during a heavy rain followed by showers and mist, (3.8 cm), it was 33 percent [Clark, 1940]. Because the rain showers in the Delta Marsh were generally less than 2 cm (Figures 23 a and b), the interception loss from the *Phragmites* was probably in the range of 30 percent to 50 percent. If it averaged 30 percent, the interception loss would be 7.3 cm and the effective rainfall then becomes 17.1 cm but at 50 percent, the effective rainfall was only 12.2 cm. Thus, about 50 percent of the seasonal evapotranspiration demand was offset by precipitation over the same period.

The mean annual precipitation for this area is 56.0 cm[1], so precipitation for the rest of the year was about 32 cm. A portion of this would be lost to the area as runoff during the spring and it is felt that total effective precipitation may be just balancing the total evapotranspiration loss during the growing season. No information is available on evaporation rates in the spring and fall but it is felt that it could be as high as 5 cm in which case the Delta Marsh may be experiencing a slight annual water deficit. The area is a discharge region in a hydrological sense [Jackson *et al.*, 1973]; any water deficit that may exist is probably cancelled by the upward movement of groundwater. Storage of runoff in bays and channels and movement of water into the marsh

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[1] Taken from Monthly Records of Meteorological Observations, 1973. Atmospheric Environment, Environment Canada.

from Lake Manitoba are probably both important in balancing annual water deficits which may occur.

During the growing season, the upward movement of ground water of either local or regional origin is of prime importance in making up the seasonal water deficit of about 15 cm. Even with this input, the net drop in the water table from June 1 to September 10 was 81 cm (Figure 36).

E. Ecological Implications of Evapotranspiration by *Phragmites*

Evapotranspiration by the *Phragmites* in the Delta Marsh was as much as 60 percent lower than that reported in other studies [Burian, 1973; Rychnovská and Smíd, 1973]. This difference may have been a reflection on the habitat, as transpiration by *Phragmites* growing on land is sometimes only 60 percent of the value for reeds growing in water [Królikowska, 1971]. Since, this species is not causing serious water deficits in the marsh on an annaul basis, its abundance will not cause the marsh to "dry-up" and therefore should not affect the present floristic composition. If the water levels of the marsh were lowered, it is felt that the *Phragmites* communities which are now established, would remain. This species is tolerant of a wide range of water regimes, communities spreading into water as deep as 50 cm, [Walker, 1965] and growing well where the water table dropped to 1 m below the surface (Site B). Because of the ability to adapt to different water regimes [Haslam, 1970] it is thought that once established, communities would probably continue to grow in regions where the water table is lower than 1 m through the whole growing season.

CHAPTER V

SUMMARY AND CONCLUSIONS

A study to examine the relationship between evapotranspiration by *Phragmites communis* and shallow groundwater table fluctuations was conducted in the Delta Marsh of Manitoba, Canada in 1970 and 1971. Two sites A and B, were chosen in *Phragmites* communities; Site A was flooded during the first month of the growing season while the water table was always below the soil surface at Site B. The density of *Phragmites* shoots was lower at Site A than B in 1971, 70.9 shoots m^{-2} and 83.8 shoots m^{-2} respectively but the density was similar in 1970 at 80 shoots m^{-2}. The understory at Site A included *Stachys palustris* and *Teucrium occidentale* with *Carex atherodes* occurring in isolated patches and at the periphery of the stand. At Site B, more understory species were present, *Urtica dioica*, *Chenopodium rubrum*, *Lycopus asper*, *Mentha arvensis*, *Stachys palustris*, *Teucrium occidentale*, *Cirsium arvense* and *Sonchus arvensis*.

Small hydrostatic lysimeters with *Phragmites* plants growing in intact soil monoliths were used to measure evapotranspiration. A water table was maintained in the lysimeters to insure a water regime similar to the stand. Representative plant growth and lysimeter exposure was realized in all installations. Evaporation from the soil or water beneath the plants was measured in a lysimeter containing a soil monolith but no living plants. Transpiration rates were determined as the difference between evaporation and evapotranspiration. Transpiration by the lysimeter plants was transposed to stand transpiration according to the ratio of the leaf area in the lysimeters to the LAI of the stand.

Evapotranspiration was found to have a July-August maximum, daily values in 1970 ranging from 1.0 to 6.5 mm day^{-1} at Site A and from 0.5 to 7.1 mm day^{-1} at Site B. In 1971, daily evapotranspiration rates were in the range of 0.4 to 6.5 mm day^{-1} at Site A and 0.7 to 5.7 mm day^{-1} at Site B. Therefore, the expected range in evapotranspiration rates by *Phragmites* communities in the Delta Marsh is up to 7.1 mm day^{-1}. Average daily evapotranspiration rates for the month of July were: Site A, 1970 - 5.0 mm day^{-1}; Site B, 1970 - 5.3 mm day^{-1}; Site A, 1971 - 3.6 mm day^{-1}; Site B, 1971 - 3.6 mm day^{-1}.

Seasonal evapotranspiration (June 1 to September 10) was estimated to be 307.8 mm at Site A and 304.7 mm at Site B almost double the effective precipitation (171 mm) during that time. The difference, 134 mm was drawn from the saturated zone in the soil and in the absence of recharge, water deficits would have occurred. Because of the hardiness of *Phragmites*, the communities would probably persist even if the saturated zone was below the rooting zone.

When the plant canopy is fully developed, transpiration accounts for 75 to 80 percent of evapotranspiration at Site A and 85 to 90 percent at Site B. The different proportions were caused by higher soil moisture content, more compacted litter layer and lower leaf area index (less shading), at Site A.

Transpiration per unit leaf area was greater than 30 ml dm^{-2} leaf day^{-1} in June 1971 dropping to a range of 0 to 20 ml dm^{-2} for July and August. As the area of senescent leaf tissue increased in September, the transpiration per unit leaf area again exceeded the normal midsummer range. The high rate in June was due to the effect of high solar energy input per unit leaf area and good wind ventilation with the low LAI as compared with conditions later in the season when the plant canopy was fully developed. The late season increase was attributable to the physical drying of the senescing leaves, possible transpiration by chlorotic leaves and inherent inaccuracies in measuring the active leaf area when the leaves were partly chlorotic.

Diurnal fluctuations in the shallow ground water table were recorded at both sites. Evapotranspiration estimates based on these fluctuations according to White [1932] were poorly correlated with lysimetric measurements when all available data were used. The general lack of correlation is explained by the high rainfall frequency, rainfall causing abnormal fluctuations in the water table. Elimination of the effect of rain was obtained during a dry period in the month of August 1970. There was a strong suggestion of a direct correlation between actual evapotranspiration and that calculated from water table fluctuations, but the latter estimate was dependent on the water table depth. It is felt that the specific yield used in the analysis may not have applied to all soil zones encountered by the phreatic surface.

A total of five meteorological parameters were measured during the two seasons, incoming short-wave radiation, net radiation, daytime air temperature, daytime wind speed and daytime relative humidity. The relationships between evapotranspiration and the meteorological variables was determined by correlation analyses. Simple correlations of evapotranspiration on short-wave radiation, net radiation and relative humidity were always significant ($p < 0.01$). Those relating wind run and evapotranspiration were not significant in any case while the correlation of evapotranspiration on temperature was only significant ($p < 0.01$) in 1970. In the multiple linear regression analyses, only short-wave radiation had a significant regression coefficient in 1970 but in 1971, short-wave radiation, net radiation and relative humidity were significant. All multiple correlation coefficients exceeded 0.80 and were significance at $p < 0.01$. To conclude, radiation and relative humidity were the foremost parameters influencing evapotranspiration rates from the *Phragmites* stands in the Delta Marsh.

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APPENDIX A

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C*********************************************************************
C       PROGRAM TO TEST DAILY MEAN AND STANDARD DEVIATION OF TEMPERATURES FROM
C      PROBES 1-9.  TESTING IN HOURLY, DAILY, AND SEMI-MONTHLY PERIODS OF TIME
C     PROBE 1  PROBE 2  . . . PROBE 9  ARE THE DIFFERENT SETS OF RECORDED TEMPS.
C     INTERVAL BETWEEN TESTING OF TEMPERATURES VARIES FROM 15 MINUTES, 1 HOUR,
C     AND  2 HOURS.
C     12 TEMPERATURES RECORDED PER DATA CARD
C     TO COMPLETE A DAY WHERE DATA IS MISSING TEMPERATURE OF 100 IS INSERTED
C*********************************************************************
      DIMENSION PROBE(2000),DAYMN(80),MAXT(31),MINT(31),PCENT(9)
      CHARACTER*40 MONTH
      REAL MEAN,INTVAL
      INTEGER DAYS,BGN,END,CHECK,COUNT,CHANGE,CORDAY,SUNRB,SUNSB
      INTEGER CHNGE1,CHNGE2
      READ,IPROBE
      WRITE(6,86) IPROBE
   86 FORMAT('+',25X,' PROBE  ',I2)
      READ32,INTVAL,DAYS,MONTH
   32 FORMAT(F4.1,I2,A30)
      READ,SUNRB,SUNSB,CHNGE1,CHNGE2,CONVT
      WRITE(6,64) SUNRB,SUNSB,CHNGE1,CHNGE2
   64 FORMAT('0','SUNRISE  ',I2,' SUNSET ',I2,'CHANGE SUNRISE ',I2,
     *' CHANGE SUNSET ',I2)
C*********************************************************************
C     NUM IS THE TOTAL OF THE NUMBER OF TEMPERATURES FOR FOR THE MONTH(DATA)
C     THAT IS BEING TESTED
C      INTVAL IS THE INTERVAL IN WHICH THE TEMPERATRES WERE BEING RECORDED
C     IE.  4--4 TEMPS RECORDED PER HOUR....1/2-- 1TEMP RECORDED EVERY TWO HOURS
C     DAYS IS THE NUMBER OF COMPLETED DAYS OF DATA FOR  ONE PERIOD(MONTH)
C     MONTH IS DATE UPON WHICH PERIOD OF TESTING BEGINS AND ENDS
C     CHNGE1 AND CHNGE2 ARE THE DAYS RESPECTIVALY ON WHICH SUNRISE AND SUNSET
C     TIMES ARE CHANGED
C     CONVT IS A CHECKING CONSTANT IF SUBROUTINE CONVER IS NEEDED
C     CONVT GREATER THAN 0 IF CONVERSION SUBROUTINE TO BE USED
C*********************************************************************
      IF(CONVT.GT.0) GOTO53
      BGN = 1
      END = 12
      NUM = 0
   57 READ(5,*,END=55) (PROBE(I),I=BGN,END)
   30 FORMAT(12F5.1)
      BGN = END + 1
      END = END + 12
      NUM = NUM + 12
      GOTO57
   53 READ,NUM
      CALL READER(NUM,PROBE)
C*********************************************************************
C    NUM IS TOTAL  NUMBER OF TEMPERATURES FOR THE PERIOD TO BE  CONVERTED
C*********************************************************************
   55 PRINT50,(PROBE(I),I=1,NUM)
   50 FORMAT(' ',24F5.1)
      WRITE(6,52) NUM,INTVAL,DAYS,MONTH
   52 FORMAT('-','AMOUNT OF DATA = ',I4,' INTERVAL IS ',F3.1,
     *'TOTAL DAYS ',I2,' OF MONTHLY PERIOD ',A30)
```

```
C***************************************************************************
C     INT1 IS THE INTERVAL OF ONE DAY OF DATA
C     PROGRAM SEGMENT TO FIND MEAN, MAXIMUM, MINIMUM OF EACH DAYS RECORDED DATA
C***************************************************************************
      INT1 = INTVAL * 24
      PRINT 21,MONTH
   21 FORMAT('-',25X,'DAILY MEANS MAXIMUMS AND MINIMUMS FOR PERIOD',A30)
      COUNT = BGN = 1
      END = INT1
      CORDAY = DAYS
      DO 7 INDEX = 1,NUM,INT1
      SUM = 0
      TEMPMN = TEMPMX = PROBE(INDEX)
      DO 5 I=BGN,END
      TEMP = PROBE(I)
      IF(TEMP.EQ.100) GOTO4
      CALL MIN(TEMPMN,TEMP)
      CALL MAX (TEMPMX,TEMP)
      SUM = SUM + TEMP
    5 CONTINUE
      DYMEAN = SUM/INT1
      WRITE(6,20) SUM,COUNT,DYMEAN
   20 FORMAT('0','SUM-',F8.2,'    MEAN FOR DAY ',I2,'----',F5.2)
      WRITE(6,28) TEMPMN,TEMPMX
   28 FORMAT(' ','MINIMUM TEMP IS--',F5.1,'    MAXIMUM TEMP IS--',F5.1)
      DAYMN(COUNT) = DYMEAN
      MAXT(COUNT)= TEMPMX
      MINT(COUNT) = TEMPMN
      COUNT = COUNT +1
      GOTO10
    4 PRINT,'INCOMPLETE DATA ON DAY ',COUNT
      CORDAY = CORDAY - 1
   10 BGN = BGN + INT1
      END = END + INT1
    7 CONTINUE
C***************************************************************************
C     PROGRAM SEGMENT TO FIND MEAN AND STANDARD DEVIATION OF MAX AND MIN TEMPS
C***************************************************************************
      SUM = SUMSQR = XSUM = XSMSQR = 0
      DO 8 J=1,CORDAY
      TEMP = MAXT(J)
      XSUM = XSUM + TEMP
      XSMSQR = XSMSQR + TEMP**2
      TEMP = MINT(J)
      SUM = SUM + TEMP
      SUMSQR = SUMSQR + TEMP**2
    8 CONTINUE
      MEAN = XSUM/CORDAY
      STNDEV = (XSMSQR -(XSUM**2)/CORDAY)/(CORDAY - 1)
      STNDEV = SQRT(STNDEV)
      WRITE(6,58) MEAN,STNDEV
   58 FORMAT('0','MEAN ',F5.2,' STANDARD DEVIATION',F5.2,
     *' FOR MAXIMUM TEMPERATURES FOR TOTAL DAYS OF PERIOD')
      MEAN = SUM/CORDAY
      STNDEV = (SUMSQR - (SUM**2)/CORDAY)/(CORDAY - 1)
      STNDEV = SQRT(STNDEV)
      WRITE(6,60) MEAN,STNDEV
   60 FORMAT('0','MEAN--',F5.2,' STANDARD DEVIATION--',F5.2,
     *'FOR MINIMUM TEMPERATURES FOR TOTAL DAYS OF PERIOD')
C***************************************************************************
```

```
C     PROGRAM SEGMENT TO FIND MEAN AND STANDARD DEVIATION OVER  TOTAL PERIOD
C*******************************************************************************
      PRINT25,MONTH
   25 FORMAT('-',25X,' OVERALL MEAN FOR MONTHLY PERIOD',A30)
      SUM = SUMSQR = 0
      DO 9 I=1,CORDAY
      TEMP = DAYMN(I)
      SUM = SUM + TEMP
      SUMSQR = SUMSQR + TEMP**2
    9 CONTINUE
      MEAN = SUM/CORDAY
      STNDEV = (SUMSQR - (SUM**2)/CORDAY)/(CORDAY - 1)
      STNDEV = SQRT(STNDEV)
      WRITE(6,22) MONTH,MEAN
   22 FORMAT('0',' MEAN FOR MONTHLY PERIOD',A30,' IS ',F5.2)
      WRITE(6,24) MONTH,STNDEV
   24 FORMAT('0','STANDARD DEVIATION FOR MONTHLY PERIOD',A30,'IS',F5.2)
C*******************************************************************************
C     PROGRAM SEGMENT TO DETERMINE MEAN AND STANDARD DEVIATION OF A PRESCRIBED
C     TIME OF A DAY OVER THE PERIOD OF DAYS.  TIME IS INCREASED BY DESIRED
C     INTERVAL AND PROCESS  REPEATED FOR COMPLETE DAY
C*******************************************************************************
      PRINT23,MONTH
   23 FORMAT('-',25X,'TIME INTERVAL MEANS FOR MONTHLY PERIOD',A30)
      INT2 = 24
      INT3 = INTVAL
      IF(INTVAL.LE.1) INT2 = INTVAL *24
      IF(INT3.LT.1) INT3 = 1
      BGN = 1
      END = INT1 * (DAYS-1) + 1
      ITIME = 24
      DO 17 KNDEX = 1,INT2
      CHECK = SUM = SUMSQR = 0
      DO 15 I =BGN,END,INT1
      TEMP = PROBE(I)
      IF(TEMP.EQ.100) CHECK = CHECK + 1
      SUM = SUM + TEMP
   15 SUMSQR = SUMSQR + TEMP**2
      IF(CHECK.EQ.DAYS) GOTO16
      SUM = SUM - CHECK*100
      SUMSQR = SUMSQR - CHECK*(100**2)
      MEAN = SUM/(DAYS -CHECK)
      STNDEV = (SUMSQR - (SUM**2)/(DAYS - CHECK))/(DAYS-CHECK-1)
      STNDEV = SQRT(STNDEV)
      WRITE(6,26) MEAN,STNDEV,ITIME,MONTH
   26 FORMAT(' ','MEAN-',F5.2,'    STANDARD DEVIATION'F7.2,'  OF TIME ',
     *I2,' HUNDRED HOURS OF MONTHLY PERIOD ',A30)
      GOTO18
   16 PRINT,'FOR TIME ',ITIME,' HUNDRED NO DATA RECORDED OVER PERIOD'
   18 IF(ITIME.EQ.24) ITIME=0
      ITIME = ITIME + 1
      IF(INTVAL.LT.1) ITIME = ITIME + 1
      BGN = BGN + INT3
      END = END + INT3
   17 CONTINUE
C*******************************************************************************
C     PROGRAM SEGMENT TO FIND PERCENT OF RECORDED DATA IN CERTAIN
C     REGULAR INTERVALS.  FOR THIS SEGMENT SUNRISE AND SUNSET TIMES ARE CONSTANT
C     TIME STARTS AT SUNRISE DAY 1
C     TIME ENDS AT SUNSET  OF LAST DAY
```

```
C     ALSO PROGRAM SEGMENT FINDS MEAN OF DAY(SUNRISE TO SUNSET) AND
C     MEAN OF NIGHT(SUNSET TO SUNRISE) .  OVERALL DAY AND NIGHT
C     MEANS AND STANDARD DEVIATIONS ARE FOUND FOR THE WHOLE MONTH
C*******************************************************************************
      WRITE(6,80) MONTH
   80 FORMAT('-',25X,'INTERVAL PERCENTAGES OF TEMPS FOR ',A30)
      WRITE(6,66)
   66 FORMAT('0',2X,'DAY',6X,'-5.0--0.0',4X,'0.1--5.0',4X,'5.1--10.0',
     *4X,'10.1--15.0',4X,'15.1--20.0',4X,'20.1--25.0',4X,'25.1--30.0',
     *4X,'30.1--35.0',4X,'35.1--40.0')
      BGN = SUNRB
      END = SUNSB
      KOUNT = 0
      DO 31 INDEX = 1,DAYS
      DO 39 L=1,2
      DO 35 J=1,9
   35 PCENT(J) = 0
      SUM = COUNT = 0
      DO 91 IJ =BGN,END
      IF(PROBE(IJ).EQ.100) GOTO47
   91 CONTINUE
      DO 33 I = BGN,END
      TEMP = PROBE(I)
      SUM = SUM + TEMP
      COUNT = COUNT + 1
      IF(TEMP.GT.25.0) GOTO43
      IF(TEMP.GT.10.0) GOTO41
      IF(-5.0.LE.TEMP.AND.TEMP.LE.0.0) PCENT(1) = PCENT(1) + 1
      IF(0.1.LE.TEMP.AND.TEMP.LE.5.0) PCENT(2) = PCENT(2) + 1
      IF(5.1.LE.TEMP.AND.TEMP.LE.10.0) PCENT(3) = PCENT(3) + 1
      GOTO33
   41 IF(10.1.LE.TEMP.AND.TEMP.LE.15.0) PCENT(4) = PCENT(4) + 1
      IF(15.1.LE.TEMP.AND.TEMP.LE.20.0) PCENT(5) = PCENT(5) + 1
      IF(20.1.LE.TEMP.AND.TEMP.LE.25.0) PCENT(6) = PCENT(6) + 1
      GOTO33
   43 IF(25.1.LE.TEMP.AND.TEMP.LE.30.0) PCENT(7) = PCENT(7) + 1
      IF(30.1.LE.TEMP.AND.TEMP.LE.35.0) PCENT(8) = PCENT(8) + 1
      IF(35.1.LE.TEMP.AND.TEMP.LE.40.0) PCENT(9) = PCENT(9)+ 1
   33 CONTINUE
      DO 37 K=1,9
   37 PCENT(K) = (PCENT(K) * 100)/COUNT
      KOUNT = KOUNT + 1
      DAYMN(KOUNT) = SUM/COUNT
      IF(L.EQ.2) GOTO45
      WRITE(6,68) INDEX,(PCENT(II),II=1,9)
   68 FORMAT(' ',1X,'DAY ',I2,4X,F6.2,4(7X,F6.2),10X,F6.2,3(8X,F6.2))
   49 BGN = END + 1
      END = SUNRB + (INT1*INDEX) - 1
      IF(INDEX.GE.CHNGE1) END=END+1
      IF(END.GT.NUM) GOTO31
      GOTO39
   45 WRITE(6,70) INDEX,(PCENT(JJ),JJ=1,9)
   70 FORMAT(' ',1X,'NIGHT ',I2,2X,F6.2,4(7X,F6.2),10X,F6.2,3(8X,F6.2))
   51 BGN = END + 1
      END = SUNSB + (INT1*INDEX)
      IF(INDEX.GE.CHNGE2) END = END - 1
      GOTO39
   47 IF(L.EQ.1) WRITE(6,72) INDEX
      IF(L.EQ.2) WRITE(6,74) INDEX
   72 FORMAT(' ','INCOMPLETE DATA  NO PERCENTAGES FOR DAY',I4)
```

```
   74 FORMAT(' ','INCOMPLETE DATA  NO PERCENTAGES FOR NIGHT',I4)
      IF(L.EQ.1)GOTO49
      IF(L.EQ.2) GOTO51
   39 CONTINUE
   31 CONTINUE
      PRINT62,MONTH
   62 FORMAT('-',25X,'SUNRISE AND SUNSET MEANS AND STANDARD DEV. FOR',
     *A30)
      K=1
   95 SUM = SUMSQR = N = 0
      DO 99 JI = K,KOUNT,2
      N = N + 1
      SUM = SUM + DAYMN(JI)
      SUMSQR = SUMSQR + DAYMN(JI)**2
      IF(K.EQ.2) GOTO97
      WRITE(6,94) N,DAYMN(JI)
   94 FORMAT(' ',5('***MEAN FOR DAY ',I2,'--',F6.2))
      GOTO99
   97 WRITE(6,96) N,DAYMN(JI)
   96 FORMAT(' ',5('***MEAN FOR NIGHT ',I2,'--',F6.2))
   99 CONTINUE
      MEAN = SUM/N
      STNDEV = (SUMSQR - (SUM**2)/N)/(N-1)
      STNDEV = SQRT(STNDEV)
      IF(K.EQ.2) GOTO93
      WRITE(6,54) MEAN,STNDEV,MONTH
   54 FORMAT('0','MEAN--',F7.2,'STANDARD DEVIATION--',F7.2,
     *'FOR DAY     TIMES OF',A30)
      PRINT,'        -------------- '
      K=2
      GOTO95
   93 WRITE(6,56) MEAN,STNDEV,MONTH
   56 FORMAT('0','MEAN--',F7.2,'STANDARD DEVIATION--',F7.2,
     *'FOR NIGHT  TIMES OF  MONTHLY PERIOD',A30)
      STOP
      END
      SUBROUTINE READER (NUM,PROBE)
      DIMENSION PROBE(2000)
      CHARACTER*80 BUFF(1)
      INTEGER END,BGN,START
      BGN = START = 1
      END = 12
    3 READ,X1,Y1,X2,Y2,NN
      PRINT,'CONSTANTS',X1,Y1,X2,Y2,NN
C************************************************************************
C    X1 Y1 X2 Y2 ARE THE CONVERSION CONSTANTS9 NN IS THE  NUMBER OF TEMPERATURES
C    BETWEEN EACH SET OF CONVERSION CONSTANTS.
C************************************************************************
      ITEMP = START + NN - 1
      IF(NN.LT.12) END = BGN + NN - 1
      IF(X1.GT.200) GOTO9
    7 READ(5,*) (PROBE(I),I=BGN,END)
   30 FORMAT(12F5.1)
      IF(END.EQ.ITEMP) GOTO5
      BGN = END + 1
      END = END + 12
      ITEMP1 = END - START
      IF(ITEMP1.GE.NN) END = ITEMP
      GOTO7
    5 L=END
```

```
      CALL CONVER (X1,Y1,X2,Y2,L,PROBE,START)
      BGN = START = END + 1
      END = END + 12
      GOTO3
    9 DO 15 K=1,NUM
      WRITE(BUFF,39) PROBE(K)
      READ(BUFF,39) PROBE(K)
   39 FORMAT(F5.1)
   15 CONTINUE
      RETURN
      END
      SUBROUTINE CONVER (X1,Y1,X2,Y2,I,PROBE, START)
      DIMENSION PROBE(2000)
      INTEGER START
      DO 3 J= START,I
      IF(PROBE(J).EQ.100) GOTO3
      PROBE(J) = (PROBE(J) - Y2)*((X1-X2)/(Y1-Y2)) + X2
    3 CONTINUE
      PRINT,(PROBE(K),K=START,I)
      RETURN
      END
      SUBROUTINE MAX (TEMPMX,TEMP)
      IF(TEMP.GT.TEMPMX) TEMPMX = TEMP
      RETURN
      END
      SUBROUTINE MIN (TEMPMN,TEMP)
      IF(TEMP.LT.TEMPMN) TEMPMN = TEMP
      RETURN
      END
```