34

INLAND WATERS BRANCH

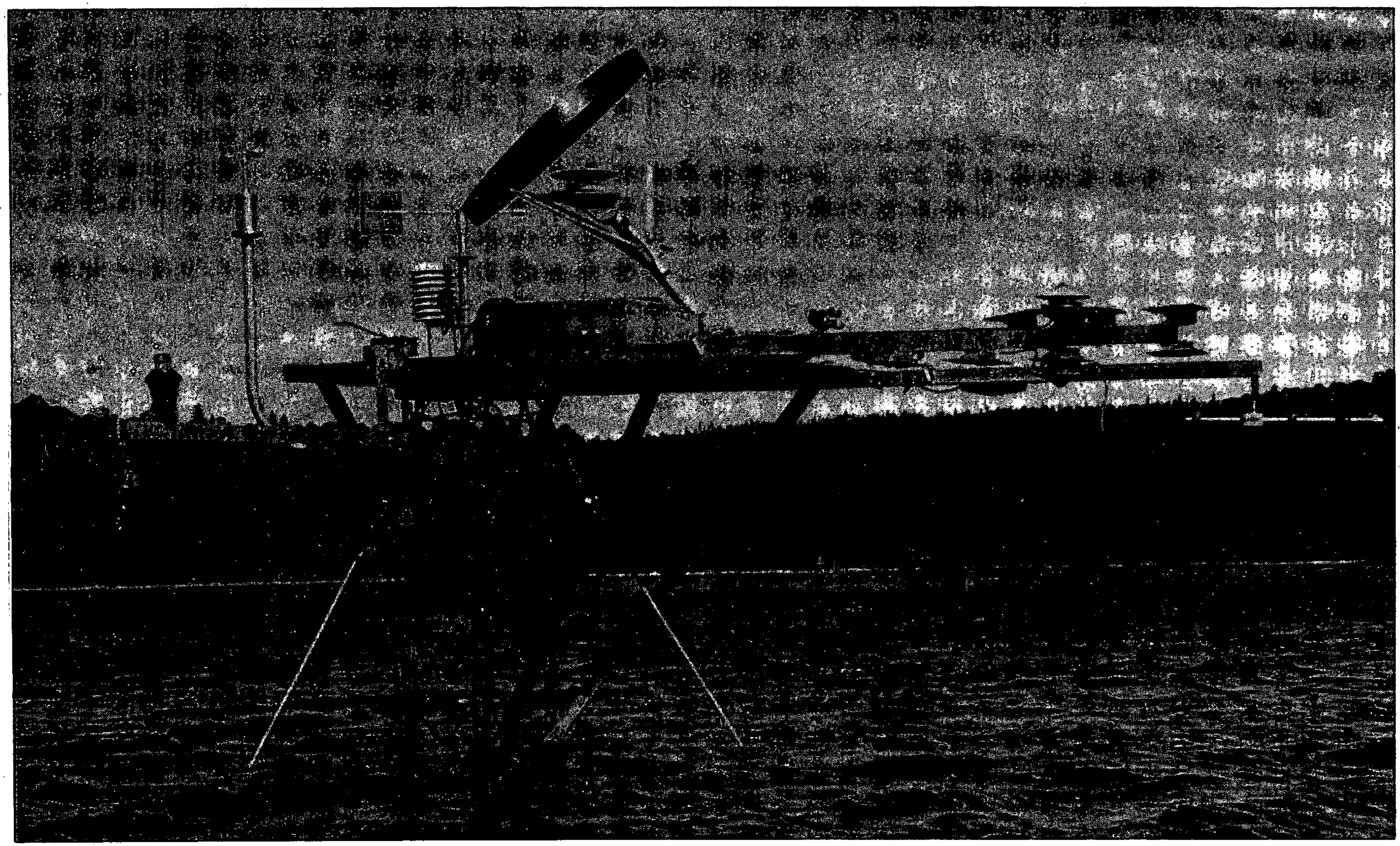
DEPARTMENT OF ENERGY, MINES AND RESOURCES

Instrumentation for Study of Energy Budget of Rawson Lake

R. CHAPIL

TECHNICAL BULLETIN NO.34

INSTRUMENTATION FOR STUDY OF ENERGY BUDGET OF RAWSON LAKE



Instrumented Rawson Lake Tower (1969)

CANADA

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OTTAWA, CANADA, 1970

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PREFACE

This report describes equipment and procedures used and contains some graphical results obtained mainly during 1969 in the Rawson Lake study, a hydrological study of a small research basin in northwestern Ontario being carried out by several Government of Canada agencies working with University of Manitoba staff.

The data collected are being used to establish climatic trends and variations, compare over-lake meteorological data with data from a Canada Department of Transport land-climatological station, determine regional radiation and energy budgets and determine the effect of radiation and meteorological factors on lake productivity.

More information on the overall scope of activities is contained in a published report on the hydrological program at Rawson Lake (Newbury and Cherry, 1970).

The author wishes to thank Mr. K. Beaty, research technician of the University of Manitoba for monitoring and service work in keeping the instruments operating; and Mrs. P. Greenway of the Canada Centre For Inland Waters, for abstracting and plotting the Rawson Lake tower data.

Instrumentation for Study of Energy Budget of Rawson Lake

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INSTRUMENTATION

Radiation

The Commonwealth Scientific and Industrial Research Organizations net pyrradiometer (Funk) used in this study measures the net vertical flux of solar plus terrestrial radiation and is mounted approximately 1.5 metres (five feet) above the surface of Rawson Lake (Frontispiece photo and Figure 1). The essential parts of the net pyrradiometer are a pair of black horizontal surfaces, one facing upward and the other downward, with thermopiles for measuring the differences in temperature between these surfaces. This instrument is linked to a Hewlett Packard strip chart recorder with a millivolt output of minus ten to plus forty.

One net pyrradiometer was installed on the Rawson Lake tower on June 20, 1969. A framework of 45 by 76 mm. (1.75 by 3.0 in.) aluminum hollow boom extending 3 metres (10 feet) from the tower center, was bolted to the tower platform. The boom was hinged at 1.5 metres (5 feet) and could be swung back to the tower for easy instrument maintenance. A system of two universals, counter-balanced by weights, provided a simple, self-leveling mounting for the net pyrradiometer (Figure 2).

The Eppley Precision Spectral Pyranometers were used in this study; one was used for the measurement of short-wave radiation from the sun and sky in the waveband of about 285 to 2800 mμ while the other was used in the inverted position to measure short-wave radiation reflected from the water.

The essential part of these pyranometers is a circular multi-junction Eppley thermopile of the recently developed wire wound type. The thermopile has the added advantage of withstanding severe mechanical vibration and shock (tested up to 20 g's with no damage to instrument). Both pyranometers were temperature compensated to ±1 per cent over the ambient temperature range -10 to +40° Celcius.

A Kipp Solarimeter was used to measure diffused incoming solar radiation. This pyranometer employs a moll thermopile consisting of fourteen copper constantan thermo junctions arranged in the form of a rectangle, approximately 14 by 10 mm. (0.55 by 0.40 in.). Direct solar rays are screened from the receiver by a sun ring. The shade ring, type I (diffusograph) was designed by the Meteorological Branch, Department of Transport (1965). The diffusograph consists of a column, clamped at its lower end to a mounting base and supporting a shade ring (Frontispiece photo). The column can be adjusted

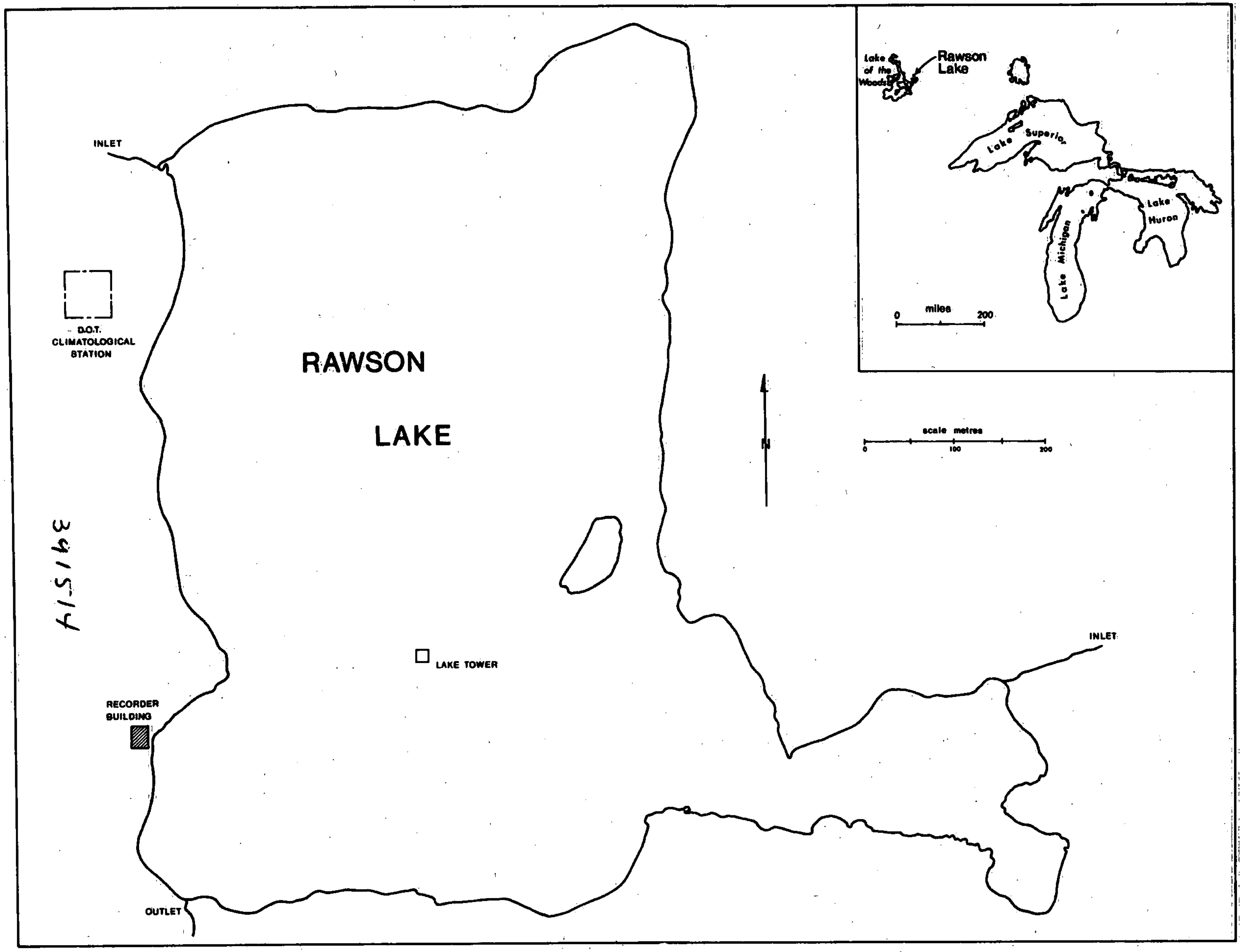


Figure 1. Rawson Lake, Ontario.

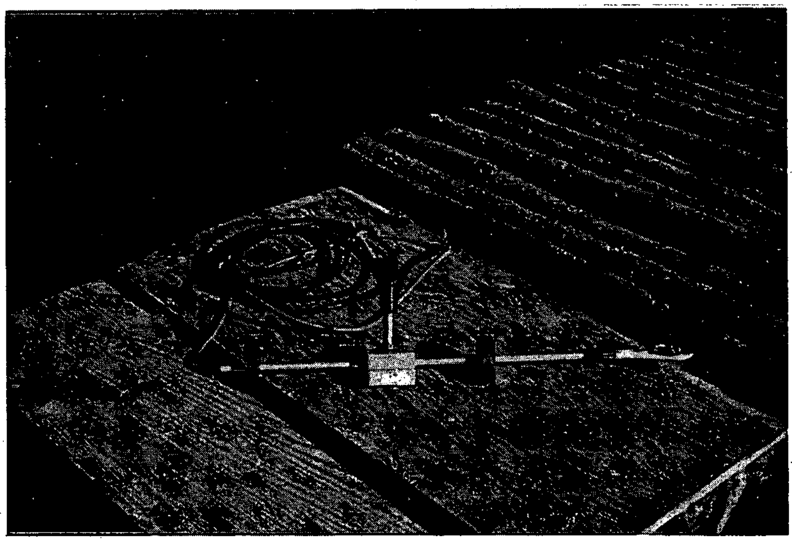


Figure 2. Universal Mounted Net Pyrradiometer.

and clamped at the desired angle to a horizontal plane to adjust for the station latitude. Clamped to the upper end of the column is an adjustable platform which holds the Kipp Solarimeter. The shade ring is supported by three arms and a collar sliding on the column. When the diffusograph is properly adjusted the shade ring prevents the direct solar rays from striking the Kipp thermopile. The position of the ring is changed periodically to compensate for variation in the sun's declination.

Plessey Meteorological Recorder

A modified Plessey meteorological recorder was used to record wind speed and direction, air temperature, relative humidity and water temperature.

The meteorological recording package was developed by the Engineering Systems section at the Canada Centre for Inland Waters, Burlington, Ontario. Because the design for the system required it, the recording package is capable of recording the meteorological parameters in a digital format on magnetic tape. The main component of the recording package is the Hymet MMI recorder, made by Plessey Electronics.

The Hymet recorder is activated by an Ergus clock which initiates a recording cycle every ten minutes. The sensor inputs are encoded by a ten-bit, serial binary number. This binary number can be any integral number between 0 and 1023.

A standard calibration for each sensor was determined which related Plessey numbers to meteorological units.

All meteorological sensors of the same type can be interchanged as long as new calibrations for each sensor are applied.

The recordings of meteorological parameters on magnetic tape can be transferred directly to a computer output. Mean hourly values of wind speed and direction, air temperature, relative humidity and water temperature are the final results. (Tables 1 and 2, July 19-22).

TABLE 1. METEOROLOGICAL MEAN HOURLY VALUES FOR JULY 19 & 20.

Hourly and Daily Averages for July 19

HOUR	WIND SPEED	WIND DIR.	AIR TEMP.	HUMIDITY	WATER TEMP.
1	3.9	35.0	16.7	80.7	22.7
2	2.8	32.7	16.7	78.0	22.6
3	2.8	345.0	16.8	78.7	22.6
4	3.4	10.9	16.5	80.5	22.5
5	3.7	346.2	16.3	80.6	22.4
6	4.3	9.8	16.0	81.8	22.4
7	1.9	58.8	16.4	78.2	22.3
8	1.6	314.2	18.3	70.8	22.4
9	2.7	100.9	18.9	71.4	22.5
10	5.0	327.0	19.3	69.1	22.5
11	5.4	350.0	19.5	67.4	22.5
12	6.6	350.7	19.7	65.7	22.6
13	7.7	7.6	20.2	61.9	22.8
14	8.3	353.9	20.3	60.5	22.8
15	7.7	349.8	20.5	59.6	22.9
16	9.4	332.8	20.8	58.6	22.9
17	9.4	334.5	20.5	59.6	22.9
18	9.9	346.2	20.4	59.6	22.9
19	9.8	352.2	19.2	65.6	22.9
20	7.1	352.5	18.7	66.3	22.8
21	5.5	342.9	17.8	70.7	22.7
22	2.8	319.2	16.4	80.5	22.6
23	2.3	26.4	15.4	87.7	22.6
24	2.6	42.0	14.8	91.4	22.5
Daily Average for Interval Considered	5.3		18.1	71.9	22.7

Averaged Wind Vector, Speed 4.8

Hourly and Daily Averages for July 20

HOUR	WIND SPEED	WIND DIR.	AIR TEMP.	HUMIDITY	WATER TEMP.
1	2.5	37.0	14.3	93.2	22.4
2	3.1	38.1	14.4	93.6	22.4
3	2.5	348.5	14.3	93.4	22.3
4	3.4	282.2	13.4	95.3	22.2
5	4.1	2.6	14.1	95.6	22.1
6	5.9	18.7	14.1	94.3	22.0
7	6.3	343.8	14.1	93.3	22.0
8	6.0	17.3	14.8	87.4	22.0
9	6.8	44.9	16.3	76.6	22.1
10	6.0	70.6	16.9	71.2	22.3
11	6.8	73.0	18.1	63.3	22.6
12	5.9	39.7	19.4	55.7	22.9
13	5.8	37.2	20.3	48.2	23.3
14	5.9	48.6	21.2	43.5	23.6
15	5.2	31.9	21.7	42.5	23.7
16	5.5	125.3	22.2	40.6	23.9
17	6.1	69.5	22.3	42.1	23.8
18	5.1	93.9	22.3	41.7	23.8
19	4.6	47.8	22.2	43.1	23.8
20	4.6	65.6	20.8	48.4	23.7
21	4.1	10.9	19.3	57.6	23.5
22	3.1	64.1	16.9	71.1	23.4
23	2.1	47.7	15.6	78.6	23.2
24	2.5	51.5	14.5	84.2	23.1
Daily Average for Interval Considered	4.8		17.6	68.9	22.9

Averaged Wind Vector, Speed 3.9 Direction 43.1

Units for Reading

Wind Speed in M.P.H.
Wind Direction in Degrees from Magnetic North
Temperatures in Degrees C
Humidity in Per Cent Saturation

TABLE 2. METEOROLOGICAL MEAN HOURLY VALUES FOR JULY 21 & 22.

Hourly and Daily Averages for July 21

HOUR	WIND SPEED	WIND DIR.	AIR TEMP.	HUMIDITY	WATER TEMP.
1	2.9	92.7	13.9	88.8	22.9
2	3.4	110.2	13.1	90.7	22.8
3	3.4	106.6	12.6	92.8	22.7
4	2.5	103.3	12.5	94.4	22.5
5	3.1	106.1	12.3	95.5	22.4
6	2.2	109.8	13.5	93.7	22.4
7	2.4	214.0	15.9	80.6	22.4
8	3.3	161.5	18.1	66.7	22.4
9	5.3	181.9	19.6	59.4	22.6
10	7.8	187.8	20.6	54.2	22.7
11	8.5	192.1	21.2	50.6	22.8
12	7.9	174.7	21.8	46.5	22.8
13	8.5	187.9	22.5	43.8	23.0
14	9.1	185.6	22.8	42.1	23.2
15	8.5	179.7	22.9	41.1	23.1
16	8.5	186.6	22.9	41.8	23.1
17	7.4	181.0	22.7	47.1	23.1
18	6.1	162.1	22.5	48.1	23.0
19	5.8	157.7	22.1	51.1	23.0
20	4.5	143.9	21.5	54.0	22.9
21	4.4	152.6	20.9	56.1	22.9
22	3.9	176.4	19.8	65.2	22.9
23	3.5	191.2	19.8	63.9	22.8
24	7.1	186.8	19.6	66.4	22.8
Daily Average for Interval Considered					
	5.4		18.9	64.0	22.8

Averaged Wind Vector, Speed 4.8 Direction 170.7

Hourly and Daily Averages for July 22

HOUR	WIND SPEED	WIND DIR.	AIR TEMP.	HUMIDITY	WATER TEMP.
1	5.7	163.1	17.6	84.6	22.7
2	7.0	173.1	16.2	92.7	22.6
3	5.3	167.8	16.1	92.8	22.5
4	5.4	161.4	16.0	91.9	22.4
5	5.3	166.0	16.1	92.1	22.4
6	5.0	148.5	16.0	91.4	22.3
7	6.0	157.3	16.8	88.3	22.3
8	6.2	155.5	17.6	83.3	22.3
9	7.5	162.2	18.7	75.0	22.4
10	9.0	178.9	19.5	68.5	22.4
11	8.6	181.9	19.8	70.0	22.4
12	7.6	180.1	19.1	76.3	22.3
13	7.4	164.5	17.0	92.5	22.3
14	5.9	150.4	16.6	94.6	22.2
15	4.7	127.5	16.7	94.8	22.2
16	5.1	112.6	16.6	94.5	22.1
17	2.5	90.5	16.6	94.9	22.1
18	2.8	170.5	17.1	93.8	22.1
19	4.1	209.2	17.6	91.8	22.2
20	3.4	186.8	17.2	93.7	22.2
21	2.4	200.5	16.9	95.3	22.0
22	2.4	213.2	16.9	94.7	22.0
23	2.4	189.7	16.8	94.5	21.9
24	2.5	220.5	16.8	95.9	21.9
Daily Average for Interval Considered					
	5.2		17.1	89.1	22.3

Averaged Wind Vector, Speed 4.7 Direction 166.8

Units for Reading
Wind Speed in M.P.H.
Wind Direction in Degrees Magnetic North
Temperatures in Degrees C
Humidity in Per Cent Saturation

To solve the problem of easy accessibility to data and to minimize maintenance problems, two multi-conductor signal cables were laid a distance of about one thousand feet under water to the Rawson Lake tower. A third cable was installed for providing AC power for monitoring work, and for emergency use of strip chart recorders on the tower.

Output signals from the radiation sensors were cabled to two multi-pen Hewlett Packard strip chart recorders.

The study of evaporation from a reasonably clear small lake surface is particularly important in this investigation. An energy balance approach to estimating evaporation employs the following equation:

$$Q_s - Q_r + Q_\ell\downarrow - Q^\ell\uparrow = \pm Q_n = Q_h + Q_e + Q_t$$

where Q_s is the short-wave radiation from the sun and sky, assumed by convention to be positive.

Q_r is the short-wave radiation reflected from the water.

$Q_\ell\downarrow$ is the long-wave radiation received by the surface from the atmosphere.

$Q^\ell\uparrow$ is the long-wave radiation emitted or reflected by the surface.

Q_n is the net all-wave radiation. A gain of energy by the surface is positive.

Q_t is the net change of heat in the lake.

Q_h is the transfer of sensible heat to the atmosphere. An upward flow of heat is positive.

Q_e is the contribution of latent heat of evaporation. An upward flow of water vapour (evaporation) is positive; a downward flow (condensation) is negative.

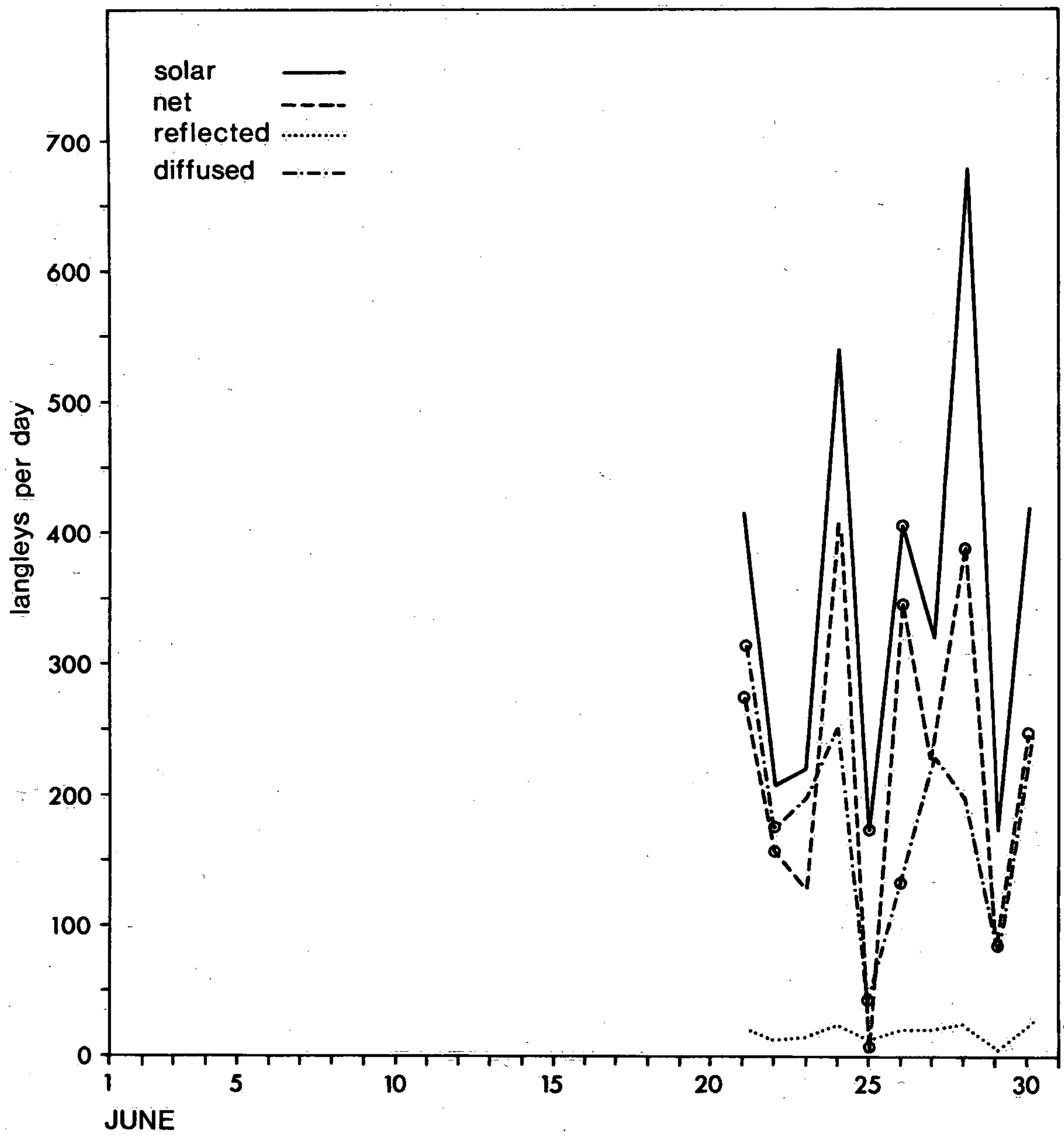
Figures 3 to 8 were plotted to establish a direct comparison of radiation in the four fields measured. Daily totals of incoming, diffused and reflected short wave, and net radiation have been established for the period June 21 to November 3, 1969.

Water Temperature

A six thermistor, battery-operated, Tele-Thermometer Y S I model 47 Indicator, with associate bridge circuitry, was used to measure winter water temperatures (Figure 9). This Y S I system has a one second response with an output accuracy of ± .15°C.

Two thermistors were placed at depths of two, six and nine metres, (6.6, 19.7 and 29.5 feet) with the first water temperature reading being taken on December 21 (Figure 10). Weekly measurements of water temperatures were maintained throughout the winter until the end of April.

Data for the depth 6 metres (19.7 feet) were not published in Figure 10, because of inconsistent results and the failure of probes 3 and 4 during recalibration.



o PARTIAL DAY OF RADIATION MEASURED

Figure 3. Rawson Lake radiation measurements (June).

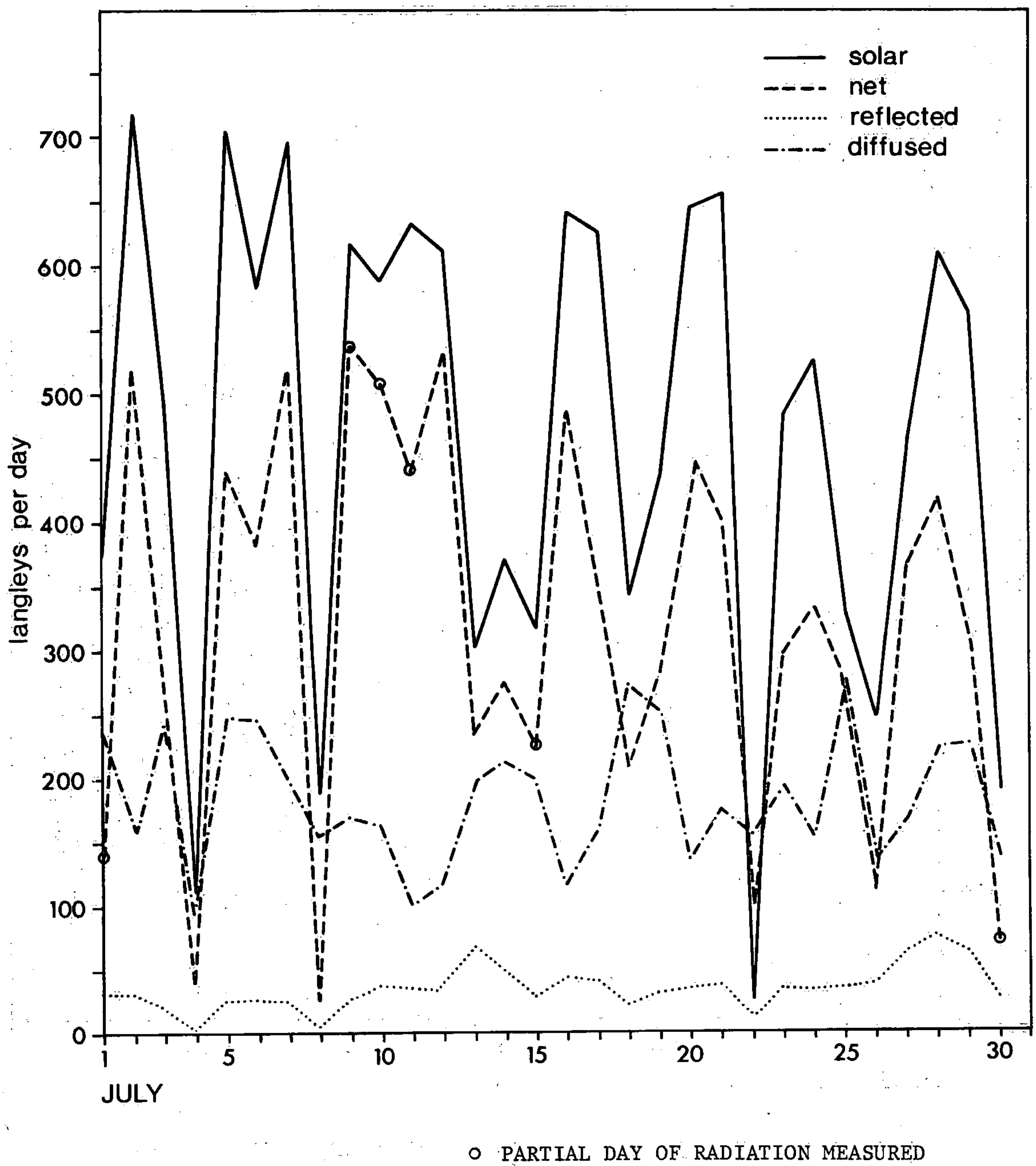
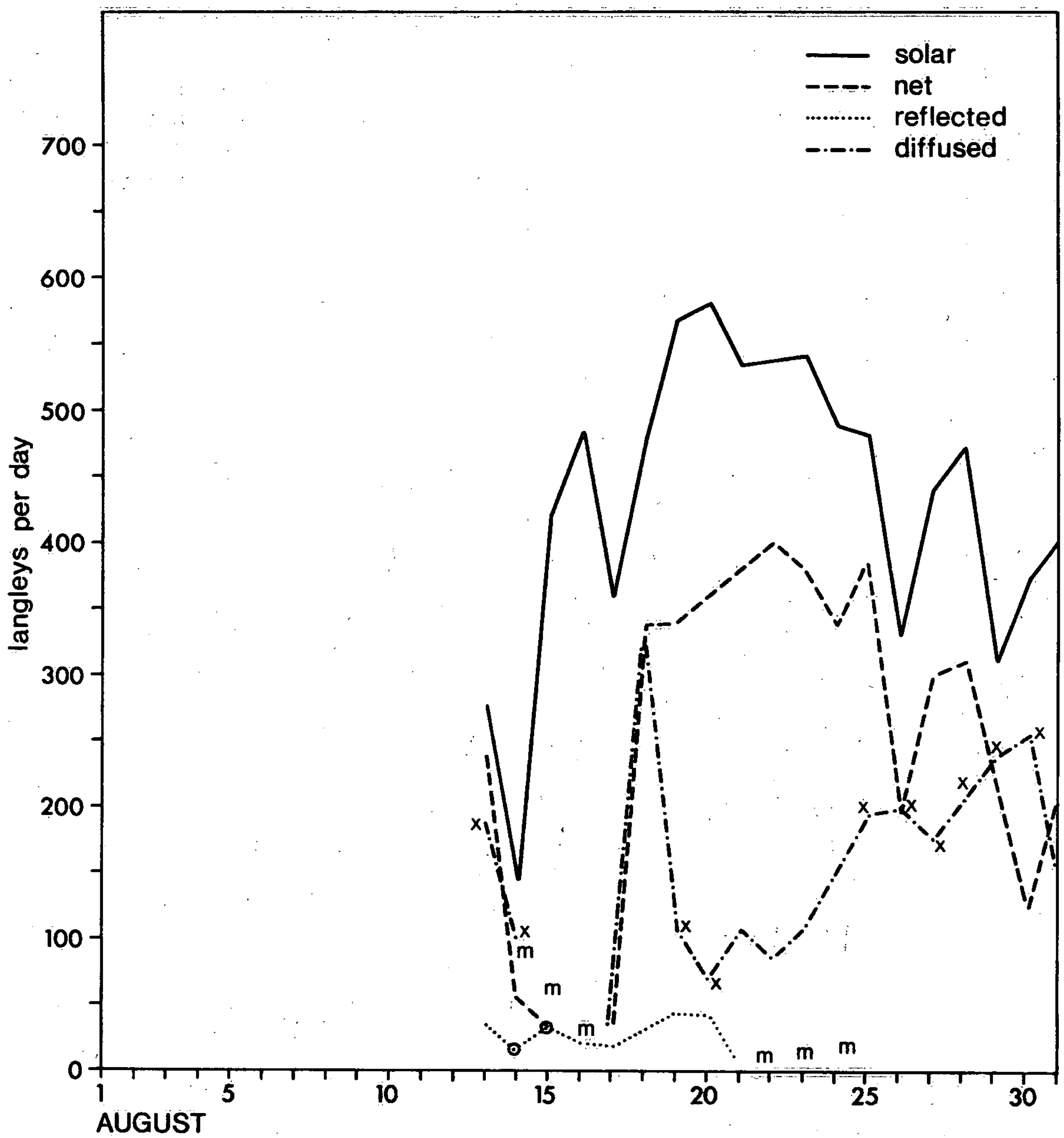


Figure 4. Rawson Lake radiation measurements (July).



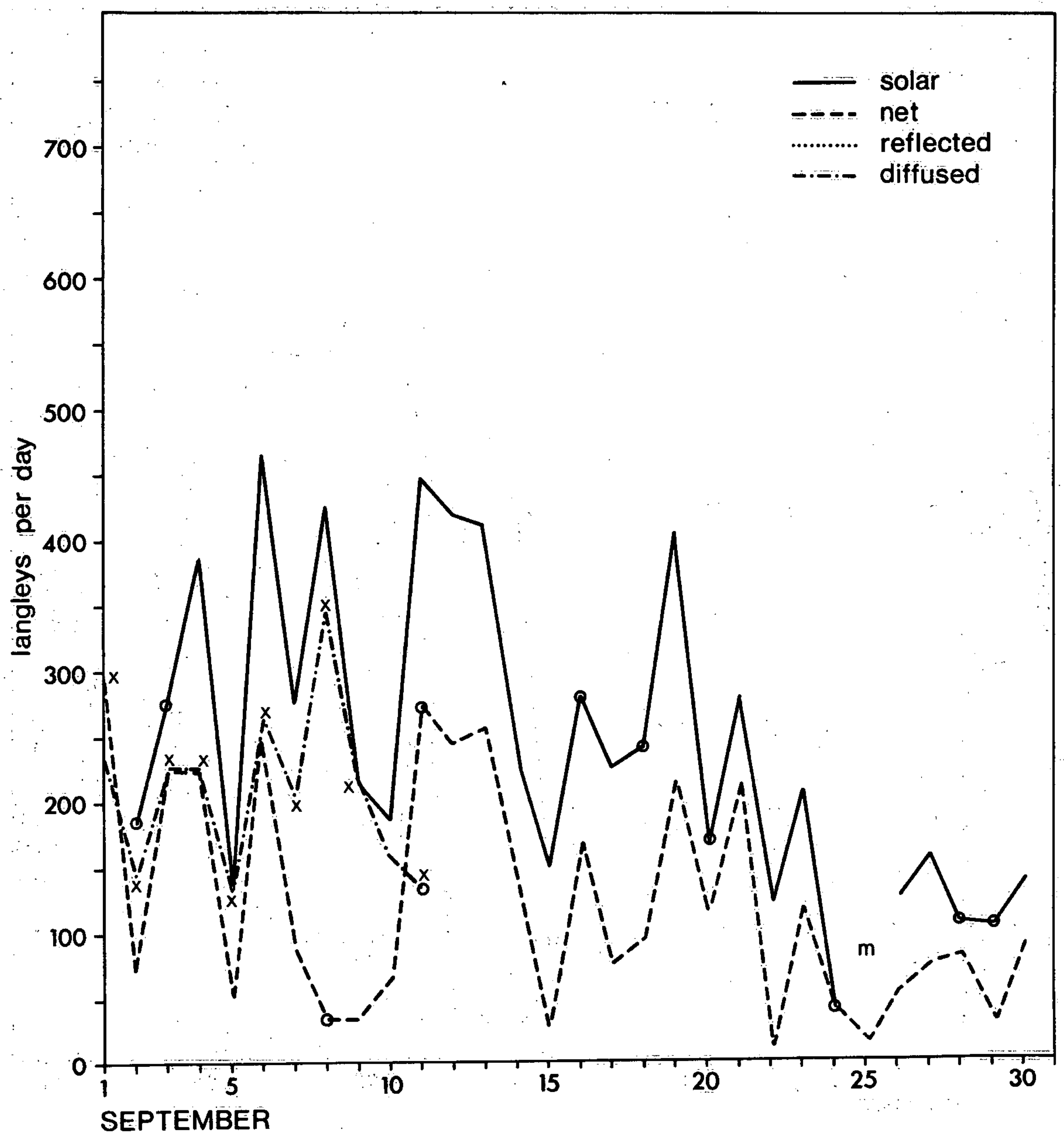
o PARTIAL DAY OF RADIATION MEASURED

x SUN SHINING ON DIFFUSED INSTRUMENT

m DATA MISSING

NO DATA FROM AUGUST 1 - 12 LIGHTNING STRUCK TOWER

Figure 5. Rawson Lake radiation measurements (August).



o PARTIAL DAY OF RADIATION MEASURED

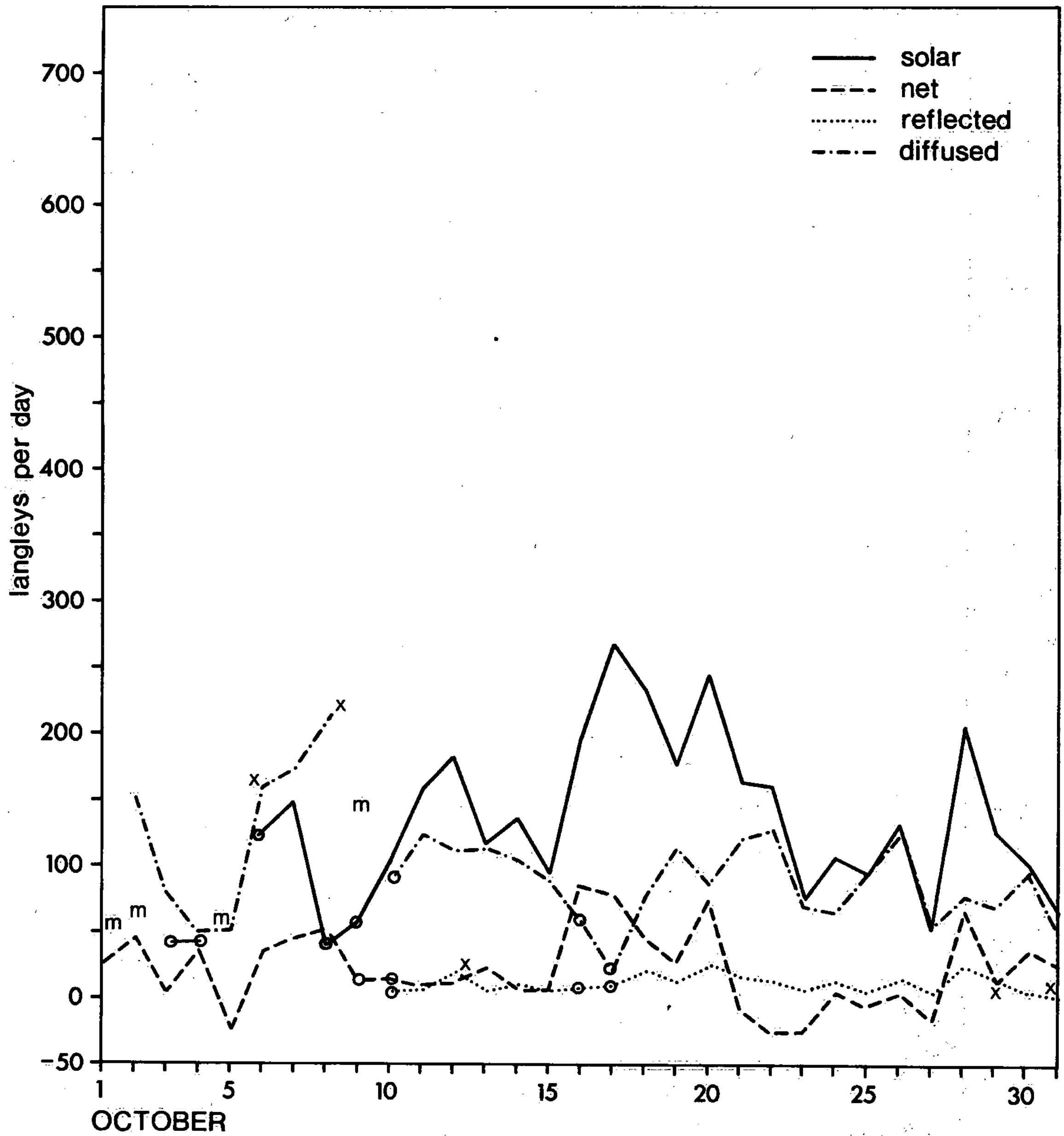
x SUN SHINING ON DIFFUSED INSTRUMENT

m DATA MISSING

REFLECTED DATA MISSING FOR SEPTEMBER

DIFFUSED DATA MISSING FROM SEPTEMBER 12 - 31

Figure 6. Rawson Lake radiation measurements (September).



o PARTIAL DAY OF RADIATION MEASURED

x REFLECTION OFF WATER

m DATA MISSING

REFLECTED DATA MISSING OCTOBER 1 - 9

Figure 7. Rawson Lake radiation measurements (October).

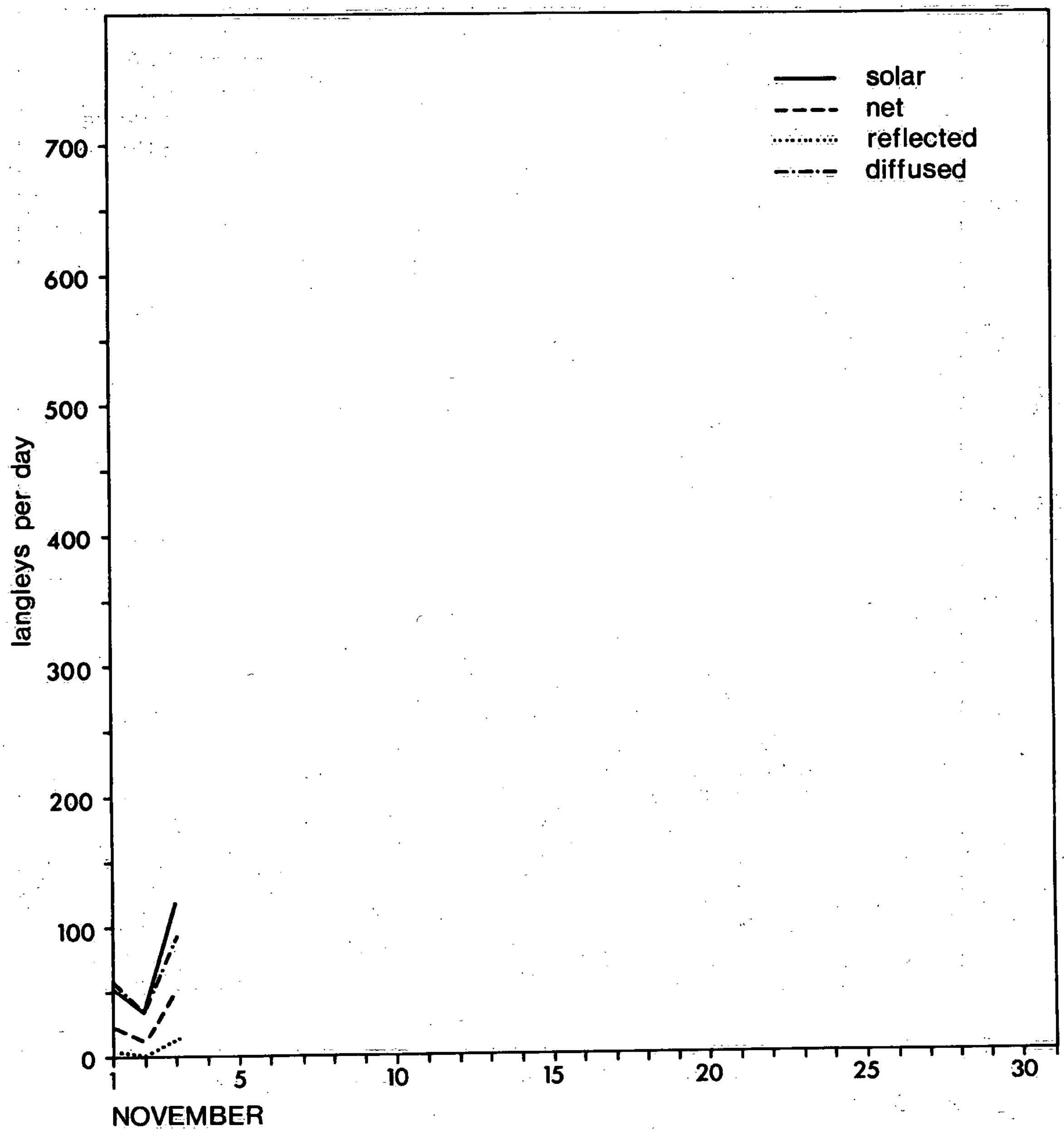


Figure 8. Rawson Lake radiation measurements (November).

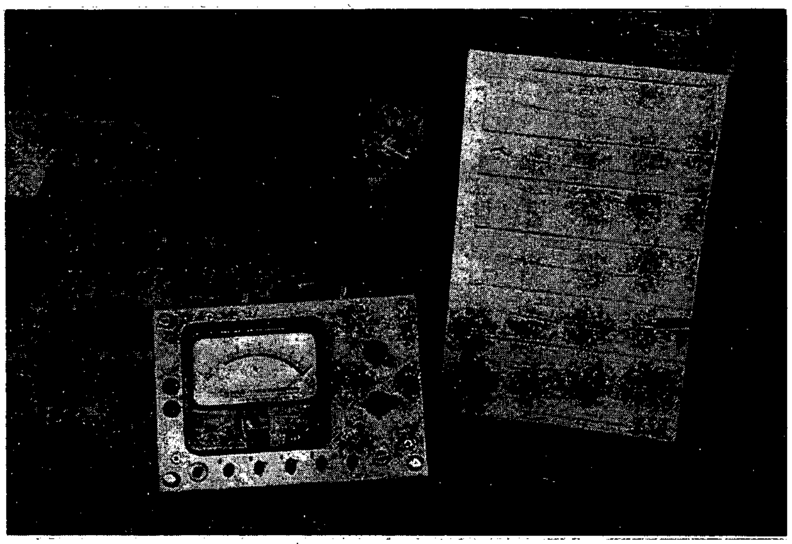


Figure 9. Tele-Thermometer Y S I Indicator

Climatological Station

The Department of Transport Climatological Station was installed in June 1969, with observations beginning in July. This station is located near the northwest corner of Rawson Lake (Figure 1), about 75 metres (246 feet) inland from the lake.

The meteorological parameters measured were maximum and minimum daily temperatures, wind direction and speed, total daily sunshine, pan evaporation, and precipitation.

In early November a short wave pyranometer was installed to record incoming solar radiation. A back-up system consisting of a model R-401 Weather Measure Corporation Actinograph was installed for periods of power or instrument failure.

MISSING DATA

The Rawson Lake tower data collection was interrupted by a lightning discharge on July 31 making all instruments inoperative until August 12. A minor electrical discharge occurred on September 12 causing further damage to the radiation sensors. The lack of reflected radiation data during August and September was caused by recorder malfunction and low unrecordable measurements.

IMPROVEMENTS IN THE CONTINUING STUDY

During the 1970-72 period a continuing program of data collection is planned, including four thermistor temperature surveys of Rawson Lake for evaluation of lake heat content.

Improvements in the collection of data during the 1970 season have been implemented. Radiation measurements will be integrated with hourly

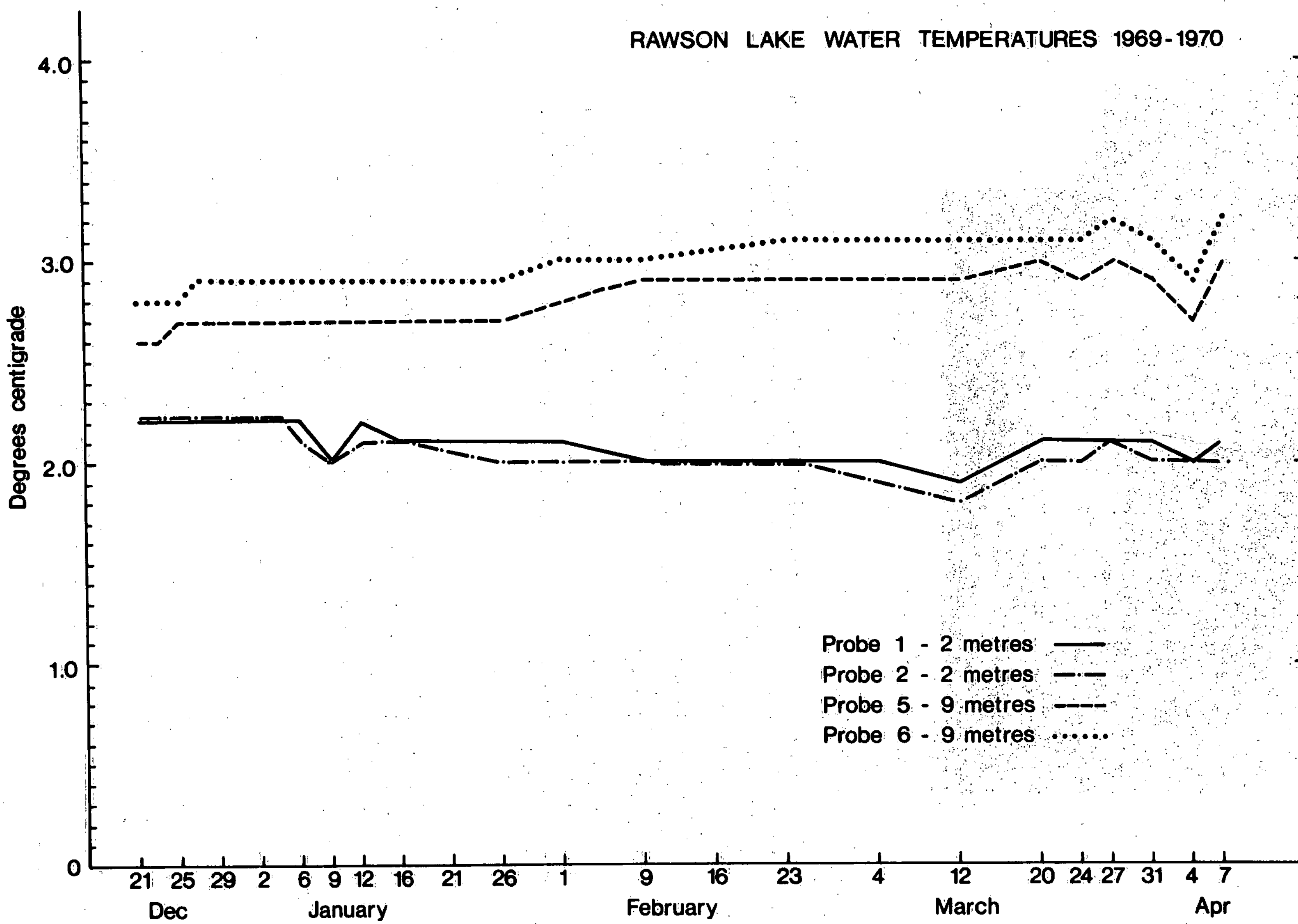


Figure 10. Rawson Lake winter water temperatures, 1969-70.

mechanical counter print-outs. Daily monitoring of all equipment and data should improve the quality and frequency of all observations. Further assurance of back-up data will be a Meteorograph recorder which will record humidity, and air and water temperature on a chart.

REFERENCES

Meteorological Branch, Department of Transport. 1965. Manual of radiation instruments and observations. Toronto, December, 1965.

Newbury, R.W. and J.A. Cherry. 1970. Kenora hydrologic research watershed program. University of Manitoba, Winnipeg.

Current Technical Bulletins

No. 22 Detergents, Phosphates and Water Pollution. W.J. Traversy, P.D. Goulden and G. Kerr, 1970.

A report on the results of chemical analyses of phosphate content in detergents and washing products. The report traces the development of washing products from organic soaps to modern phosphate-based detergents and describes the relationship between phosphates and the eutrophication process.

No. 23 Regional Groundwater Flow Between Lake Ontario and Lake Simcoe. C.J. Haefeli, 1970.

A report on the hydrogeological conditions to the north of Toronto with a view to determining if the terrestrial water balance of the Lake Ontario Basin is affected by a major seepage from Lake Simcoe.

No. 24 Application of Regression Analysis in Hydrology. N. Tywoniuk and K. Wiebe, 1970.

A description of the applications (and limitations) of regression analysis and a discussion of the distinction between regression - and correlation analysis.

No. 25 Stream Gauging Techniques for Remote Areas Using Portable Equipment. M. Church and R. Kellerhals, 1970.

A review of streamflow measuring techniques applicable to rivers with peak flows up to 10,000 cfs.

No. 26 The Control of Eutrophication. Prepared by staff of the Canada Centre For Inland Waters, Burlington, Ontario; Fisheries Research Board of Canada, Winnipeg; Inland Waters Branch, Ottawa, 1970.

A discussion of the respective roles of phosphorus, nitrogen and carbon as critical elements in limiting the eutrophication process.

No. 27 An Automated Method for Determining Mercury in Water. P.D. Goulden and B.K. Afghan, 1970.

A report describing a method for determining the mercury content in water containing mercury concentrations as low as 0.05 μg/l.

No. 28 An Assessment of the Wave Agitation in the Small Boat Basin at the Canada Centre For Inland Waters. T.M. Dick, 1970.

A discussion of the results obtained from a model study of wave action in the small boat basin at the Canada Centre For Inland Waters, Burlington, Ontario.

No. 29 Measurement of Discharge Under Ice Conditions. P.W. Strilaeff and J.H. Wedel, 1970.

An outline of the difficulties encountered in the measurement of discharge under ice cover and a discussion of a possible technique for estimating river discharge using a single velocity in a cross-section.

No. 30 Prediction of Saturation Precipitation of Low Solubility Inorganic Salts from Subsurface Waters under Changing Conditions of Total Concentration, Temperature and Pressure. R.O. van Everdingen, 1968.

A report containing graphs that enable the determination of the degree of (under- or over-) saturation of aqueous solutions with respect to $BaSO_4$, $CaSO_4$, $SrSO_4$, BaF_2, CaF_2 and MgF_2 under a variety of conditions of temperature, pressure, and total salt concentrations. Also presented are examples of the influence of temperature changes, dilution, evaporation, addition of common salt, and mixing, on the degree of saturation of the above solutions.

No. 31 A Hydrologic Model of the Lake Ontario Local Drainage Basin. D. Witherspoon, 1970.

A discussion of a hydrologic model proposed for the Lake Ontario local drainage area. The basic principles used in the model are those of water and energy balances. Using estimates of actual evaporation, realistic values of the regional moisture are obtained which, when routed, simulate the measured outflow.

No. 32 Identification of Petroleum Products in Water. A. Demayo, 1970.

A description of an extraction method used in the Water Quality Division laboratory to analyze water samples, and activated carbon samples through which water has been passed, for the presence of crude oil or other petroleum product.

No. 33 Seasonal Variations, Sulphur Mountain Hot Springs, Banff, Alberta. R.O. van Everdingen, 1970.

A study of seasonal variations in the physical and chemical parameters of the sulfurous hot springs on Sulphur Mountain, near Banff, Alberta. In the absence of accurate discharge measurements, only a "minimum required" mixing ratio could be calculated, leading to minimum ion concentrations and a minimum temperature for the cooler water.

A complete list of titles in the Technical Bulletin Series and copies of any of these publications may be obtained from the Director, Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa, Ontario.