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WEED RESEARCH ORGANIZATION

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A PERMANENT AUTOMATIC WEATHER STATION USING DIGITAL INTEGRATORS

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BEGBROKE HILL, YARNTON, OXFORD

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NOTE

SIMMONS, R.C. A permanent automatic weather station using digital integrators. _Tech. Rep. agric. Res. Coun. Weed Res. Orgn_, 1974, (33), pp 12.

A PERMANENT AUTOMATIC WEATHER STATION USING DIGITAL INTEGRATORS

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SUMMARY

An automatic weather station for use on permanent sites is described; wet and dry bulb air temperatures, soil temperatures, light, windspeed and rainfall are recorded.

Digital integrators are used to obtain true mean values, and since only one set of values is punched each hour, only a short length of paper tape is produced. This tape can be read into a distant computer via a telephone line in a few minutes, so that it is feasible to produce daily printed weather summaries.

Computer programs have been developed to read, check, scale and summarise the information, and the program set has been made flexible so that special calculations can be easily done.

Sources of error and malfunction in outdoor recording equipment, and ways of minimising their effects, are discussed.

INTRODUCTION

At the Weed Research Organization information on the weather is used in the conduct and interpretation of field experiments, for the forecasting of irrigation needs and for the collection of records throughout the year as a guide for experimenters wishing to simulate outdoor conditions in controlled environment facilities. To this end standard meteorological observations have been taken daily for a number of years. There have been several attempts to introduce automatic recorders in one form or another to permit the estimation of average values of factors such as soil temperatures and light intensity and to allow experimenters to observe how such factors vary during critical periods of an experiment. The first method used for continuous recording employed a multipoint chart recorder to record air and soil temperatures only. This recorder proved mechanically unreliable, and the charts were difficult to read. Later a set of integrators with a paper strip printer were used to record temperatures, and another strip printer and integrator were added to record light intensity, using a Kipp solarimeter. The strip printers were easier to read than the chart records, but it was impossible to scale the output so that real values appeared on the printout. The accuracy of these instruments was not good, mainly due to the use of poor quality amplifiers to match the transducers to the integrators. To overcome these difficulties a system of automatic recording was specified which embodied the following features:

1) Automatic recordings to be made of hourly means of the following factors:

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* Herbicide Group

light intensity, dry bulb temperature, wet bulb temperature, soil temperature at 3 different depths, wind speed and rainfall.

2) Provision to be made for the addition of further measuring instruments to the system for special purposes.

3) The instrument to be constructed as much as possible from standard manufacturers' modules, specially adapted if necessary, to reduce design effort.

4) The output to be of a form suitable for direct computer processing, to yield an immediate summary correctly scaled and easily intelligible together with daily means, maxima and minima.

This last requirement was made easier by the introduction of a fast-operating programming language "BASIC" on the Rothamsted ICL 4/70 computer. Using the remote access terminal at WRO which is connected to the computer by Post Office landline, we have written programs which allow a day's punched output from the recorder to be transmitted to the computer, converted to real values and the summary printed on the terminal within a few minutes. There are other programs to store abbreviated summaries of the day's recordings and to plot simple graphs or do special calculations, such as assessment of the suitability of the day for spraying.

DESIGN

One option open to those wishing to obtain a data logging system is to buy a fast-scanning logger, add suitable sensors, and use a computer to derive average values from a large number of instantaneous readings.

While frequent sampling has merit in that it records events lasting only a short time, this was considered of little importance for meterological work, and the production of large quantities of information, a necessary consequence of fast sampling, only leads to a greater likelihood of a fault in the data. It was therefore decided to use a different method in which the signals are averaged before punching (Figure 1). The anemometer and rain gauge have switch mechanisms contained within them, and it is only necessary to count the switch closures occurring in a given time in order to obtain an average value. The measurements of light and temperature are derived in an analogue form so digital integrators are used to convert the analogue signal to a stream of slow pulses whose rate is proportional to the signal level (Bailey, 1969). These pulses can then be counted in the same way as the rain and wind signals.

EQUIPMENT

Main Electronics

Time Electronics digital integrators are used to digitise temperature and light readings. These are conveniently available in racks of five. Two racks were used in the instrument, giving the capacity to integrate up to 10 channels. Six are used for standard meteorological measurement, the other four are available for use with additional sensing devices for special purposes. The counter unit, serialiser and punch are supplied by ESL as a custom-made unit. Each of the 12 channels has a three-decade counter and therefore a maximum count of 999 and a theoretical resolution of 0.1%. To achieve this resolution it is necessary to adjust the

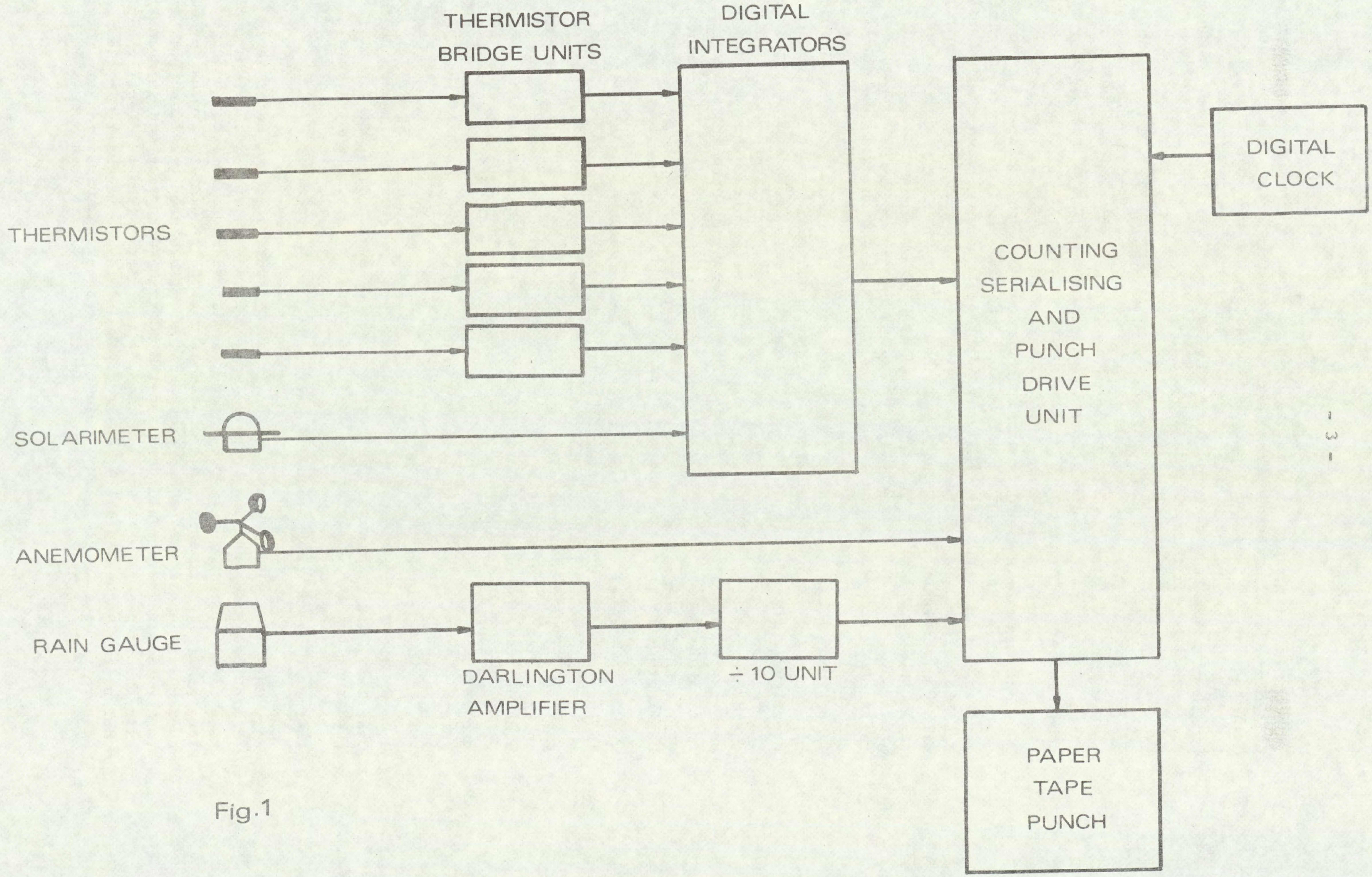

THERMISTOR
BRIDGE UNITS
DIGITAL
INTEGRATORS
THERMISTORS
SOLARIMETER
ANEMOMETER
RAIN GAUGE
DARLINGTON
AMPLIFIER
÷ 10 UNIT
COUNTING
SERIALISING
AND
PUNCH
DRIVE
UNIT
DIGITAL
CLOCK
PAPER
TAPE
PUNCH

Fig.1

integrator count rates so that the highest expected reading gives near to 999 counts per hour. Each hour, a digital clock starts a punch sequence during which the time and counter readings are punched onto the tape and the counters are reset. After the last punching each day (midnight) a length of blank tape is produced by the machine so that the met. observer can easily detach the previous day's tape.

Sensors

1. Light. A Standard Kipp Solarimeter is uded. This gives an output which is substantially linear over a wide range of light intensities, and can therefore be connected directly to the integrator.

2. Rain. We have found it difficult to obtain a reliable automatic rain gauge of sufficient resolution for our purposes. None of the commercially available rain gauges were entirely suitable, as they lacked the 0.1 mm resolution required by some WRO users. We were advised by other users, mainly river authorities, that small bucket tipping gauges were not very reliable. We therefore chose an 0.5 mm/tip gauge by Casella. However this gauge did not prove sufficiently reliable, and in an attempt to improve both reliability and resolution, we removed the bucket mechanism from the gauge and substituted a gauge head designed by Young (Young, 1973) and made in our laboratory. This gave about 100 counts per mm so resolution was adequate, but accuracy remained a problem. The gauge contains a reservoir whose overflow is formed into drops, which are counted; expansion of the water in the reservoir caused overflow to appear at times when there was no rain. We therefore modified the design to use a small reservoir. This appears to be an improvement but at the time of writing it has not been installed for sufficient time to estimate its long-term accuracy. A diagram of this very simple gauge and its associated relay driving circuit (a conventional Darlington Amplifier) is shown in Figure 2.

3. Temperatures. All temperatures are measured using Grant miniature thermistors connected to bridge/linearisers supplied by Grant. These give an approximately linear ($\pm$ 2%) output over the range -20 to +30^{o}C. (Thermistors are not inherently linear devices, but they do not require such thick cables as metal resistance thermometers, so long runs of cable are considerably cheaper.) Individual corrections can be made during computer processing if greater accuracy is required. Wet and dry bulb thermisters are selected for matching characteristics to improve the accuracy of humidity determination. New thermistors may require a settling down period (Beck, 1956; Hyde, 1971) though we did not find this.

4. Wind. The anemometer is a standard Met Office pattern manufactured by Casella. This particular instrument gives 20 switch closures per mile of wind run, but the computer converts its output to metric equivalents.

Installation and cables

Care has to be taken to ensure that moisture does not enter cable terminations and junction boxes. Cable joints are best avoided where possible, for instance by obtaining thermistors with leads of suitable length already attached, so that the only cable connection is inside the shed which houses the recording apparatus. (This shed provides protection for the instrument transducers and the punching mechanism and is maintained within suitable temperature limits by a ventilator fan and electric heater controlled by thermostats.) Where cable joints are necessary in the field we have found it desirable to solder the connections, individually insulate

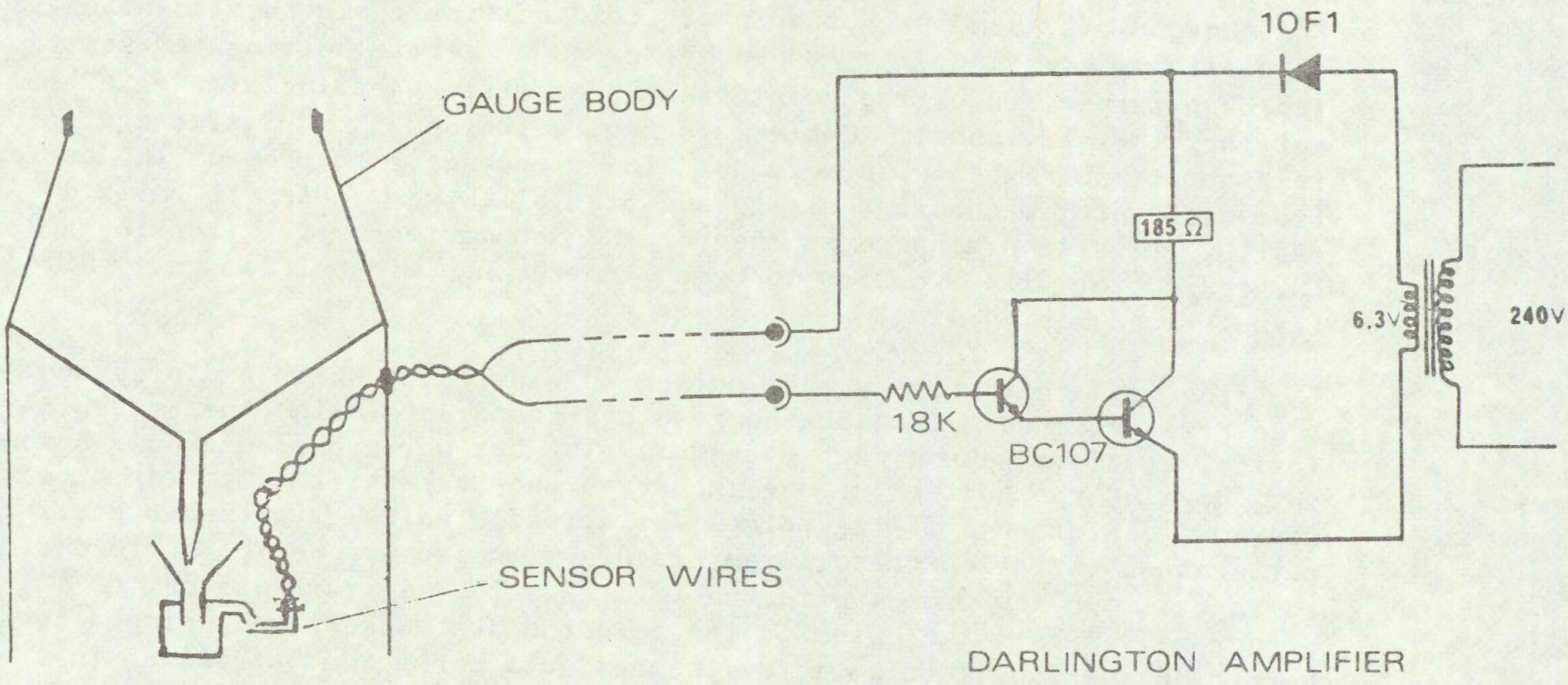


Fig. 2 MODIFIED YOUNG RAIN GAUGE

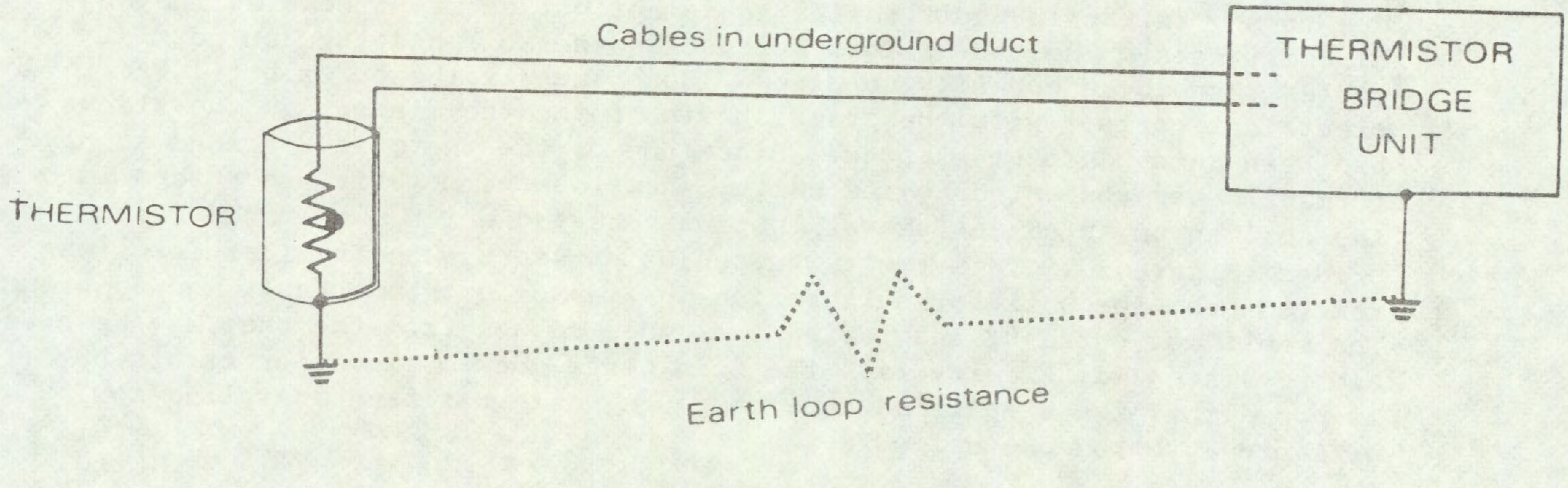


Fig.3 EARTH LOOP ERROR IN SOIL THERMISTORS

and encapsulate them in a proprietary cold-setting resin such as standard 'Araldite'. Its viscosity can be decreased by gentle heating to assist thorough permeation of the joint, though excessive heating will make the setting time very short. Cables are buried inside 75 mm plastic drainpipes laid about 150 mm below the ground. The pipes serve to protect the cables from accidental mechanical damage and also allow new cables to be laid easily. Plastic drainpipe is cheaper than conduit or metal trunking and the large diameter allows cables to be pulled through without damage. (Site layout - see Fig. 4.)

The soil thermometers were buried in a new plot which had previously been grass covered. To make the readings comparable with other meteorological stations we wanted a bare soil plot but our experience had shown that digging the soil to remove the grass and bury the thermometer probes caused a disturbance of the normal soil profile which gave uncharacteristic patterns of variation of soil temperature with depth. We therefore decided to install our new probes with the least possible disturbance of the soil structure. First, the grass on the selected plot was killed using a contact herbicide, paraquat, followed by the residual herbicide 'atrazine' to prevent regrowth. A small core of soil was carefully removed using a coring tool and the thermistors pushed as far as possible into the wall of the hole at the desired depth. The core was then replaced and the cables from the thermistors were led out on top.

Physical assembly of the various electronic modules used in the system was easy because all the sub-units were in standard 19-inch racks (we assembled the thermometer units and their power supply into a 19-inch rack prior to assembly, using a commercial sub-rack).

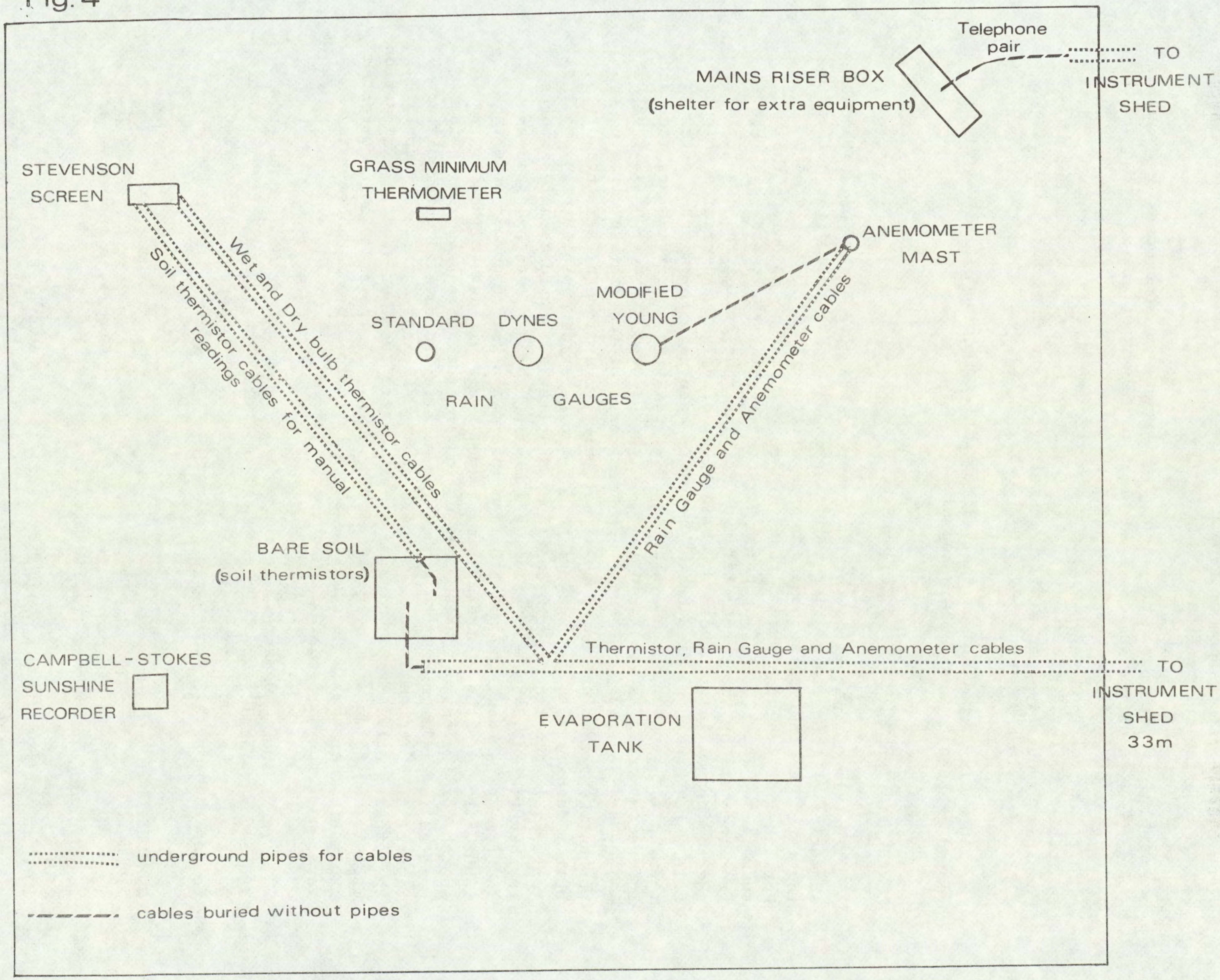
EXPERIENCE IN USE

The equipment has been in operation for nine months at the time of writing. The instruments gave some trouble when first installed, mainly due to transient pulses generated by the heating system, which caused some of the logic to latch up in a fault condition. Zero-voltage switching relays, and mains filters, were fitted to eliminate this problem. One fault which was experienced on the soil thermometers is interesting. This was not due to any intrinsic fault in the equipment but due to a combination of circumstances. The thermistors for use in the soil had thicker coaxial cables than those normally supplied. Consequently the outer braid was in electrical contact with the steel sheath of the thermistor, as the sleeve had been removed to save space. Since one of the thermistor bridge supply terminals was connected to the earth, when the thermometer was pushed into the soil an unwanted resistance loop was created which unbalanced the bridge (Figure 3). This fault was confusing since when the thermistor was removed from the soil for calibration in a water bath, no fault was apparent. The fault was cured by insulating the cable screen from the sheath. We have had persistent difficulty with the rain gauge due to expansion errors but it is hoped that the simplified type of gauge which has been installed now will prove to be more reliable.

When the cables were installed, a spare pair was run between the site and the instrument shed. This pair has proved invaluable in tracing faults since it can not only be used as a telephone line but as a return loop to test continuity, or as a temporary stand-by line if a fault occurs on one of the other cables. Apart from the faults mentioned most of the troubles experienced have been with the sensors and some time each month has to be

Fig. 4

LAYOUT OF WRO MET SITE



given over to maintenance or repair of the sensors and their cables, as well as routine calibration.

The paper tape punch has also given trouble on some occasions usually due to foreign matter such as dead flies or pieces of grass landing on the feed spool of the tape and being carried into the mechanism and jamming it. A cover has now been made for the punch to prevent this happening. There is still room for improvement in the reliability of the system but it compares favourably with similar installations on other sites (Brockway, 1973; Hardwicke and Wood, 1973).

Appendix 2 contains an analysis of faults recorded in a three month period grouped by cause where known.

CONVERTING THE VALUES TO A READABLE FORM

The aim of installing the equipment was to give easily understandable summaries of the main weather factors as soon as possible after collecting the tape. We therefore chose programs written in "BASIC", a simple Fortran-like language with a fast turn-round time, to calculate the summaries. The ICL 4/70 computer at Rothamsted stores the values read in from the tape by the remote teletype terminal and scales the quantities, checks for unlikely values or combinations of values and creates an output file which can be printed on the teletype machine a few minutes after reading the tape. Derived values such as relative humidities are included in the summary. The tests included in the program are for unlikely values of any factor i.e. outside the expected range of the British climate, or for unlikely combinations such as wet bulb temperature higher than dry bulb. Warning messages are printed on the teletype console if any of the tests fail, but the program continues despite test failures unless there is insufficient data. If values are missing for any reasons, such as instrument failure, the operator can insert a negative number onto the input file in place of the missing value. This will cause the program to search for the nearest value present and interpolate a value which is printed in the summary with a question mark to indicate an interpolated figure. (See Appendix 1.) If there is insufficient data to interpolate, the program will set the missing items to zero together with an exclamation mark to denote an unrecoverable missing item. If there are no uncorrected faults in the summary, a command can be typed to store an abbreviated version of the day's data for future reference.

These short summaries are formed into files of one month each and stored on magnetic tape. The command to store the data in fact starts a series of programs and any special calculations which may be required can be included in this sequence.

CONCLUSIONS

1) The equipment fulfils most of the design criteria, although we are working to improve the reliability.

2) The use of standard manufacturers' items wherever possible simplified the construction and reduced the time needed to start the system working.

3) The small quantity of paper tape produced each day can easily be read into a remote computer using an on-line remote access terminal via

Post Office lines. This is a major factor favouring the use of digital integrators.

4) Using the computer to print a simple readable summary encourages experimenters to make full use of the information.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. D. Coupland, Dr. J.C. Caseley and Dr. K. Holly for their useful discussion in the preparation of this report, and I. Maslen for carrying out the acceptance tests and writing some of the programs. Program development has been continued by W. Jenkins of the A.R.C. Letcombe Laboratory.

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BECK, A. (1956) The stability of thermistors. J. Sci. Inst., 33, 16.

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ENVIRONMENT LAB. MET. PROGRAM.

MET SUMMARY FOR 31/01/74

TIME	DRY BULB	WET BULB	SOIL 1.5 CM	SOIL 2.5 CM	SOIL 5 CM
1.00	8.6	7.2	4.9	6.4	6.8
2.00	6.9	5.0	4.0	5.6	6.3
3.00	5.7	4.2	3.0	4.6	5.6
4.00	5.1	3.6	2.3	3.7	4.9
5.00	4.9	3.8	2.1	3.5	4.7
6.00	4.2	3.2	1.2	2.7	4.1
7.00	3.4	2.4	0.7	2.1	3.5
8.00	2.8	2.0	0.3	1.7	3.1
9.00	4.8	3.5	0.5	1.7	3.0
10.00	6.0	4.5	0.9	2.2	3.2
11.00	7.5?	5.6?	2.4?	3.7?	4.3?
12.00	8.9?	6.6?	3.8?	5.2?	5.4?
13.00	10.3	7.7	5.2	6.6	6.5
14.00	10.4	7.5	5.8	7.3	7.1
15.00	10.3	7.3	5.9	7.3	7.5
16.00	10.0	6.9	5.6	7.0	7.4
17.00	8.9	6.3	4.7	6.3	7.1
18.00	7.7	5.7	3.8	5.3	6.3
19.00	7.1	5.3	3.0	4.5	5.7
20.00	7.1	5.3	3.0	4.3	5.4
21.00	7.1	5.3	3.0	4.2	5.3
22.00	7.1	5.4	3.1	4.1	5.1
23.00	7.1	5.5	3.0	3.9	5.0
0.00	7.1	5.5	2.9	3.9	4.9
MEAN	6.95	5.14	3.13	4.49	5.39
MAX	10.4	7.7	5.9	7.3	7.5
MIN	2.8	2.0	0.3	1.7	3.0

TIME	LIGHT W/SQ.M	WIND M/S	R.H. %	V.P.D. MB	RAIN MM
1.00	6	8.4	83	0.90	0.0
2.00	5	4.8	75	1.24	0.0
3.00	4	5.0	78	1.03	0.0
4.00	5	5.1	79	0.99	0.0
5.00	4	2.8	84	0.71	0.0
6.00	2	2.0	84	0.72	0.0
7.00	4	1.5	86	0.61	0.0
8.00	6	1.3	86	0.58	0.0
9.00	28	3.2	82	0.84	0.0
10.00	175	4.4	79	1.01	0.0
11.00	244?	5.1?	76?	1.26?	0.0?
12.00	313?	5.7?	73?	1.51?	0.0?
13.00	381	6.3	69	1.76	0.0
14.00	216	5.5	67	1.95	0.0
15.00	131	6.5	66	1.99	0.0
16.00	97	6.1	65	2.01	0.0
17.00	22	4.4	69	1.67	0.0
18.00	4	4.3	74	1.38	0.0
19.00	4	4.7	75	1.25	0.0
20.00	4	6.1	76	1.21	0.0
21.00	5	6.1	76	1.21	0.0
22.00	4	5.5	78	1.11	0.0
23.00	5	5.5	80	1.03	0.0
0.00	4	5.6	80	1.03	0.0
MEAN	50.6	4.79	77	1.19	(TOTAL)
MAX	381	8.4	86	2.01	0.0
MIN	2	1.3	65	0.58	

TOTAL RUN OF WIND= 235.5 MILES = 379.1 KM.

END OF MET. SUMMARY FOR 31/01/74

? = VALUES INTERPOLATED BY PROGRAM

Appendix 2 Faults in automatic recording system between January 1 1974 and March 31 1974

Fault	Number of occurrences	Notes
Loss of data due to transient pulses from shed temperature controllers	17	This fault was eventually cured by using zero-voltage switching relays in shed temperature controls
Solarimeter faulty due to rain water entering	8	This was caused by the outer dome of the solarimeter loosening. It was not detected until the dome blew off
Rain gauge inaccurate due to reservoir expansion	7	Checked against Dynes recording gauge. The instrument has been redesigned
Rain gauge fails to work at all	1	A faulty 'weatherproof' plug and socket (supplied with gauge)
Cable faults in soil thermistors	4	It is impossible to extend protection pipe very close to soil thermistors or measurements will be disturbed. There is therefore a section of cable vulnerable to mechanical damage.
Cable faults in wet and dry bulb thermistors	2	Damage to exposed portion of cable believed to be caused by hares
Earth loop in soil thermometers	1	See text
Cables damaged by shed moving in wind	1	At 2.00 pm on January 11 1974 an abnormally high gust of wind caused the shed to shift by 2 ft pulling cables out of pipe and causing a rack of equipment to fall from bench
Tape jammed in punch	2	Caused by dirt carried into punch on tape

Appendix 3 List of equipment and suppliers

Unit	Supplier
Main electronic unit, comprising electronic counters, digital clock, encoding and punch drive circuitry) Paper tape punch)	Enquiry Systems Ltd, Halifax Road, High Wycombe, Bucks
Digital integrators type TSM in 19" racks with power supply and monitor meter	Time Electronics Ltd, Botany Industrial Estate, Tonbridge, Kent
Thermometer cards type SRB/ic) Power supply for above) Thermistors for above)	Grant Instruments (Developments) Ltd, Toft, Cambridge
19" rack cabinet, plinth subrack assembly for thermometers, miscellaneous racking	F.T. Davis Ltd, Kings Langley, Herts
Plugs, sockets, miscellaneous electronic components for rain gauge	R S Components Ltd, 13 Epworth Street, London EC2P 2HA
Kipp solarimeter type CM4	Shandon Southern Instruments, 65 Pound Lane, Willesden, London NW10
Rain gauge W5254) Anemometer W1252)	Casella Ltd, Regent House, Britannia Walk, London N1 7ND
Divider unit for rain gauge pulses Electromatic SM145	Radiatron Ltd, 76 Crown Road, Twickenham, Middlesex
Zero voltage switching relays for shed temperature controllers - Electronic relay type A2410	Farnell Electronic Components, Canal Road, Leeds, LS12 2TU
Cables (Thermistors were ordered complete with cable.) Ordinary twisted twin 7/0076 PVC insulated cable is the cheapest, and satisfactory for switching devices like the anemometer. For signal cables where some degree of screening is required, a coaxial cable such as Reliance 502A, CW 154B or similar can be used	Reliance Cords and Cables, Leyton, London E10

ABBREVIATIONS

ångström	Å
Abstract	Abs.
acid equivalent*	a.e.
acre	ac
active ingredient*	a.i.
approximately equal to*	≃
aqueous concentrate	a.c.
bibliography	bibl.
boiling point	b.p.
bushel	bu
centigrade	C
centimetre*	cm
concentrated	concd
concentration	concn
concentration × time product	ct
concentration required to kill 50% test animals	LC50
cubic centimetre*	cm^3
cubic foot*	ft^3
cubic inch*	in^3
cubic metre*	m^3
cubic yard*	yd^3
cultivar(s)	cv.
curie*	Ci
degree Celsius*	°C
degree centigrade*	°C
degree Fahrenheit*	°F
diameter	diam.
diameter at breast height	d.b.h.
divided by*	÷ or /
dry matter	d.m.
emulsifiable concentrate	e.c.
equal to*	=
fluid	fl.
foot	ft
freezing point	f.p.
from summary	F.s.
gallon	gal
gallons per hour	gal/h
gallons per acre	gal/ac
gas liquid chromatography	GLC
gramme	g
hectare	ha
hectokilogram	hkg
high volume	HV
horse power	hp
hour	h
hundredweight*	cwt
hydrogen ion concentration*	pH
inch	in.
infra red	i.r.
kilogramme	kg
kilo (×10^3)	k
less than	<
litre	l.
low volume	LV
maximum	max.
median lethal dose	LD50
medium volume	MV
melting point	m.p.
metre	m
micro (×10^{-6})	µ
microgramme*	µg
micromicro (pico: ×10^{-12})*	µµ
micrometre (micron)*	µm (or µ)
micron (micrometre)*×	µm (or µ)
miles per hour*	mile/h
milli (×10^{-3})	m
milliequivalent*	m.equiv.
milligramme*	mg
millilitre	ml

× The name micrometre is preferred to micron and µm is preferred to µ.

millimetre*	mm
millimicro* (nano: $\times 10^{-9}$)	n or mμ
minimum	min.
minus	-
minute	min
molar concentration*	M (small cap)
molecule, molecular	mol.
more than	>
multiplied by*	×
normal concentration*	N (small cap)
not dated	n.d.
oil miscible concentrate	o.m.c. (tables only)
organic matter	o.m.
ounce	oz
ounces per gallon	oz/gal
page	p.
pages	pp.
parts per million*	ppm
parts per million by volume*	ppmv
parts per million by weight*	ppmw
percent(age)*	%
pico (micromicro: $\times 10^{-12}$)	p or μμ
pint	pint
pints per acre	pints/ac
plus or minus*	±
post-emergence	post-em.
pound	lb
pound per acre*	lb/ac
pounds per minute	lb/min
pound per square inch*	lb/in^2
powder for dry application	p. (tables only)
power take off	p.t.o.
precipitate (noun)	ppt.
pre-emergence	pre-em.
quart	quart
relative humidity	r.h.
revolution per minute*	rev/min
second	s
soluble concentrate	s.c.
soluble powder	s.p.
solution	soln
species (singular)	sp.
species (plural)	spp.
specific gravity	sp. gr.
square foot*	ft^2
square inch*	in^2
square metre*	m^2
square root of*	$\sqrt{\ }$
sub-species*	ssp.
summary	s.
temperature	temp.
ton	ton
tonne	t
ultra-low volume	ULV
ultra violet	u.v.
vapour density	v.d.
vapour pressure	v.p.
varietas	var.
volt	V
volume	vol.
volume per volume	v/v
water soluble powder	w.s.p. (tables only)
watt	W
weight	wt
weight per volume*	w/v
weight per weight*	w/w
wettable powder	w.p.
yard	yd
yards per minute	yd/min

* Those marked * should normally be used in the text as well as in tables, etc.

AGRICULTURAL RESEARCH COUNCIL

WEED RESEARCH ORGANIZATION

Technical reports available

5. A survey of the problem of aquatic weed control in England and Wales. October, 1967. T.O. Robson. Price - £0.25.

6. The botany, ecology, agronomy and control of Poa trivialis L. rough-stalked meadow-grass. November 1966. G.P. Allen. Price - £0.25.

7. Flame cultivation experiments 1965. October, 1966. G.W. Ivens. Price - £0.25.

8. The development of selective herbicides for kale in the United Kingdom. 2. The methylthiotriazines. Price - £0.25.

9. The post-emergence selectivity of some newly developed herbicides (NC 6627, NC 4780, NC 4762, BH 584, BH 1455). December, 1967. K. Holly and Mrs. A.K. Wilson. Price - U.K. and overseas surface mail - £0.25; overseas airmail - £0.50.

10. The liverwort, Marchantia polymorpha L. as a weed problem in horticulture; its extent and control. July, 1968. I.E. Henson. Price - £0.25.

11. Raising plants for herbicide evaluation; a comparison of compost types. July, 1968. I.E. Henson. Price - £0.25.

12. Studies on the regeneration of perennial weeds in the glasshouse; I. Temperate species. May, 1969. I.E. Henson. Price - £0.25.

13. Changes in the germination capacity of three Polygonum species following low temperature moist storage. June, 1969. I.E. Henson. Price - £0.25.

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