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Evaporation Memorandum No 41

The variation of winter half-year hydrologically effective rainfall and summer half-year potential soil moisture deficit at Kew.

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Summary. Winter ½-year hydrologically effective rainfall and summer ½-year potential soil moisture deficit are proposed as appropriate variables for use in water resource studies. Data for Kew Observatory are used to evaluate these two derived variables from 1871 to 1976 and the results are subjected to simple frequency analyses. The monthly and 2-monthly distributions of hydrologically effective rainfall in the winter ½-year are studied. Suggestions are made for future 2-season analyses.

1. Introduction.

In the combined analysis of rainfall and potential evaporation (evaporative demand) as an aid to water resource planning a difference must be recognized between winter and summer rainfall in the context of changes in underground water storage. It is assumed in this paper that the majority of winter ½-year (Oct-Mar) rainfall makes some contribution to aquifer rechange and that the majority of summer ½-year (Apr-Sep) rainfall is used up in evaporation and in contributing to plant bulk. Hence in the present analysis two ½-years are considered separately. For October to March the quantity studied is hydrologically effective rainfall on grassland at Kew (Wales-Smith 1976) and for April to September the quantity studied is potential soil moisture deficit at Kew (Wales-Smith, 1977). The former is defined as rainfall minus potential evaporation when the soil is at field capacity and the second as potential evaporation minus rainfall. If crops are to transpire at the potential rate the upper limit of irrigation need is given by potential soil moisture deficit.

2. Processing monthly estimates of hydrologically effective rainfall (HER)

2.1 Estimating the return period of 1 to 6-month HER

The monthly values of HER in Wales-Smith (1976) are given in Table 1 as totals accumulated over 1 to 6 winter ½-year months. The Table 1 totals are ranked in Table 2 and the formula $P = \frac{m-0.31}{n+0.38}$ recommended by Jenkinson (1969) where

m is the ranking order
n is the number of data
and p is the cumulative probability

used to plot the data in Figure 1. (left-hand families of curv^s).

2.2 Rating a selection of HER data using Figure 1

The Table 1 values of cumulative HER for the winter ½-year 1966-7 to 1975-6 were rated interims of return period (τ) from Figure 1 and the results are plotted as return periods of 1 to 6-month accumulated HER in Figure 2. Positive values of τ are excess HER (above average) and negative values are deficiencies.

This process could easily be extended to provide frequency statistics of the occurrence of consecutive pairs of wet or dry winters in terms of HER.

The machinery for rating <u>total</u> rainfall in the manner used, above, for HER has been provided by Tabony (1977a).

2.3 Time profiles of HER

It is of interest to examine the distribution of HER in the winter $\frac{1}{2}$-year. The monthly HER data from Wales-Smith (1976) are expressed as percentage of each winter's total HER in Table 3. The way in which each winter month contributed to winter $\frac{1}{2}$-year HER is shown in Figure 3. The percentages in Table 3 are combined, in consecutive pairs, in Table 4. Figure 4 has been plotted from the 2-month percentages of Table 4 and given a rough impression of the occurrence of different types of profiles of winter $\frac{1}{2}$-year HER. Considering the central 2-months, December and January, on 90% of occasions this pair contributed $\geqslant$ 20% of winter HER and on 50% of occasions the pair contributed $\geqslant$ 54% of the total and so on. The first pair, October and November contributed relatively little HER; less than 10% on 50% of occasions. The last pair of months contributed more generously then the first pair but much less so than the central pair.

3. Processing month-end estimates of potential soil moisture deficit (PSMD)

3.1 Estimating the return periods of month-end PSMD

The end-of-September values of PSMD given in Wales-Smith (1977) (Appendix 1) are given in Table 5 and ranked in Table 6. The values expected to be reached but not exceeded and expected to be reached or exceeded with given return periods were obtained as in 2.1 and are plotted on the right hand section of Figure 1. Values of end-of-May to end-of-August PSMD are also plotted in terms of return period of attainment or exceedance using the results in Table 1 of Wales-Smith (1977). This diagram gives an idea of the frequency statistics of the limits of irrigation need for agriculture.

It would be possible to provide frequency statistics of the occurrence of a summer $\frac{1}{2}$-year with high PSMD following a winter $\frac{1}{2}$-year with low HER. Tabony (1977 b) presents four objective methods of drought analysis and uses the same data from Kew as have been used in the present study to evaluate his indices.

August 1977

References

Wales-Smith B S	1976	Hydrologically effective rainfall on grassland at Kew Observatory 1871-1976. Evaporation Memorandum 33. Unpublished material, Meteorological Office Library.
Wales-Smith B S	1977	Potential soil moisture deficit at Kew 1698-1976. Evaporation Memorandum 38. Unpublished material, Meteorological Office Library.
Jenkinson A F	1969	Statistics of extremes. Geneva, World Meteorological organization. Estimation of maximum floods. Tech Note No 98, Geneva, pp 183-227.
Tabony R C	1977a	The variability of Long-duration Rainfall over Great Britain. Meteorological Office. Scientific Paper No 37 HMSO Land. 40 pp
Tabony R C	1977b	Drought classifications and a study of droughts at Kew Met Mag 106 pp 1-10.

Table 1.

October to March Hydrologically Effective Rainfall at Kew on grassland 1871–1976 (Totals for 1 to 6 months mm).

		0	1	2	3	4	5	6	7	8	9
OCT	187		0	0	0	0	0	0	0	15	1
OCT-NOV			0	51	2	16	59	0	6	71	13
OCT-DEC			0	139	12	42	82	125	38	100	30
OCT-JAN			54	188	31	121	102	240	64	165	40
OCT-FEB			60	211	46	133	139	270	85	255	86
OCT-MAR			60	220	46	139	173	297	86	255	90
	188	98	0	33	0	0	26	0	0	0	0
		135	51	82	12	0	93	0	0	58	12
		213	114	130	24	0	121	79	31	93	41
		227	142	180	71	0	205	115	47	112	89
		281	167	256	94	54	216	121	61	152	106
		312	170	256	111	69	217	131	101	161	115
	189	0	43	35	0	0	0	15	0	0	0
		0	85	100	0	60	43	35	0	0	22
		0	153	128	51	107	86	108	0	48	49
		0	158	157	119	139	94	149	0	99	118
		0	182	210	144	139	94	196	0	143	187
		0	182	210	161	139	132	250	7	143	188
	190	0	0	0	115	0	0	0	0	0	0
		0	0	0	152	0	0	35	13	0	0
		0	0	4	187	0	9	81	101	0	48
		16	10	54	240	24	91	94	140	12	85
		30	20	62	287	25	124	114	153	12	141
		47	37	88	291	82	130	116	184	45	153
	191	0	0	12	0	0	0	9	52	4	0
		0	2	43	19	0	19	105	77	53	0
		75	109	103	34	123	146	160	103	101	0
		100	189	161	41	218	171	181	174	186	45
		120	207	174	91	285	234	186	183	231	46
		134	245	183	163	293	312	203	183	283	51
	192	0	0	0	1	37	14	0	13	0	0
		0	0	0	35	85	48	44	75	0	41
		43	0	0	85	155	116	48	164	56	147
		84	0	21	146	194	173	90	238	72	209
		84	15	80	146	261	220	166	266	76	218
		84	43	109	146	261	220	189	274	76	228

	0	1	2	3	4	5	6	7	8	9
193	0	0	17	0	0	0	0	0	0	0
	11	30	82	0	0	51	5	0	0	93
	55	37	40	0	8	103	39	72	73	112
	78	75	70	0	25	195	127	119	173	170
	105	75	125	0	64	225	215	119	181	201
	105	75	159	0	65	225	264	119	183	259
194	0	0	0	0	0	0	2	0	0	0
	85	15	2	0	28	0	93	0	0	43
	106	51	56	0	58	0	141	0	11	77
	164	98	171	29	95	25	172	24	29	92
	199	116	199	34	124	65	196	49	41	161
	256	128	199	34	124	75	283	49	48	161
195	0	0	0	0	0	0	18	0	11	0
	22	44	44	0	27	0	18	0	54	0
	55	80	109	0	71	0	71	39	127	15
	126	123	127	15	113	71	100	81	180	51
	244	137	150	54	131	71	163	124	180	81
	291	176	150	75	131	73	163	124	187	95
196	36	0	0	0	0	0	0	0	23	0
	121	0	0	15	0	4	5	2	52	0
	168	44	39	27	0	95	70	55	120	0
	221	109	50	34	0	118	98	106	179	44
	258	115	52	37	0	169	132	121	207	67
	258	115	69	96	0	169	145	121	241	81
197	0	0	0	0	7	0				0
	28	0	0	0	132	23				12
	63	4	0	0	154	48				55
	125	51	0	24	225	56				100
	130	87	0	78	244	62				128
	147	103	0	87	283	62				139

Median values or τ = 2yrs.

Table 2 Data from Table 1 ranked HER mm

		0	1	2	3	4	5	6	7	8	9
OCT	0		115	98	52	43	37	35	35	33	26
	1	23	18	17	15	15	14	13	12	11	9
	2	7	4	2	1	1	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0				
OCT	0		152	135	132	121	105	100	93	93	93
NOV	1	85	85	85	82	77	75	71	60	59	58
	2	54	53	52	51	51	51	48	44	44	44
	3	43	43	43	41	35	35	35	32	30	28
	4	28	27	23	22	22	19	19	18	16	15
	5	15	13	13	12	12	11	6	6	5	5
	6	4	2	2	2	2	0	0	0	0	0
	7	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0				
OCT	0		213	187	168	164	160	155	154	153	147
DEC	1	146	141	139	130	128	127	125	123	121	120
	2	116	114	112	109	109	108	107	106	103	103
	3	103	101	101	100	95	93	86	85	82	81
	4	80	79	77	75	73	72	71	71	70	63
	5	58	56	56	55	55	55	51	51	49	48
	6	48	48	48	44	43	42	41	40	39	39
	7	39	38	37	34	31	30	27	24	15	12
	8	11	9	8	6	4	4	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0				

OCT		0	1	2	3	4	5	6	7	8	9
JAN	0		240	240	238	227	225	221	218	209	205
	1	195	194	189	188	186	181	180	180	179	174
	2	173	173	172	171	171	170	165	164	161	158
	3	157	149	146	142	140	139	127	127	126	125
	4	123	121	119	119	118	118	115	113	112	109
	5	106	102	100	100	99	98	98	95	94	94
	6	92	91	90	89	85	84	81	78	75	72
	7	71	71	70	64	56	54	54	51	51	50
	8	47	45	44	41	40	34	31	29	29	25
	9	25	24	24	24	21	16	15	12	10	0
	10	0	0	0	0	0	0				
OCT	0		287	285	281	270	266	261	258	256	255
FEB	1	244	244	234	231	225	220	218	216	215	211
	2	210	207	207	201	199	199	196	196	187	186
	3	183	182	181	180	174	169	167	166	163	161
	4	153	152	150	146	144	143	141	139	139	137
	5	133	132	131	130	125	124	124	124	121	121
	6	120	119	116	115	114	106	105	94	94	91
	7	87	86	85	84	81	80	78	76	75	71
	8	67	65	64	62	62	61	60	54	54	52
	9	49	46	46	41	37	34	30	25	20	15
	10	12	0	0	0	0	0				
OCT	0		312	312	297	293	291	291	283	283	283
MAR	1	274	264	261	259	258	256	256	255	250	245
	2	241	228	225	220	220	217	210	203	199	189
	3	188	187	184	183	183	183	182	176	173	170
	4	169	163	163	161	161	161	159	153	150	147
	5	146	145	143	139	139	134	132	131	131	130
	6	128	124	124	121	119	116	115	115	111	109
	7	105	103	101	96	95	90	88	87	86	84
	8	82	81	76	75	75	75	73	69	69	65
	9	62	60	51	49	48	47	46	45	43	37
	10	34	7	0	0	0	0				

Table 3. Monthly grassland HER at Kew as % of Oct-Mar totals (mm).

	0	1	2	3	4	5	6	7	8	9
187		0	0	0	0	0	0	0	6	1
		0	23	4	12	35	0	7	22	14
		0	41	21	19	13	42	38	11	19
		90	22	42	57	11	39	29	25	11
		10	10	33	9	22	10	25	36	51
		0	4	0	3	19	9	1	0	4
188	31	0	13	0	0	12	0	0	0	0
	12	29	19	11	0	31	0	0	35	10
	25	38	19	10	0	13	61	30	22	26
	4	16	19	43	0	39	27	16	12	42
	18	15	30	21	78	5	4	14	25	14
	10	2	0	15	22	0	8	40	6	8
189	ø	23	16	0	0	0	6	0	0	0
	ø	23	31	0	44	33	8	0	0	12
	ø	38	13	31	34	32	29	0	34	15
	ø	3	14	42	22	6	17	0	36	37
	ø	13	26	16	0	0	18	0	30	36
	ø	0	0	11	0	29	22	100	0	0
190	0	0	0	40	0	0	0	0	0	0
	0	0	0	12	0	0	30	7	0	0
	0	0	4	12	0	7	40	48	0	31
	34	27	58	19	29	63	11	21	27	24
	30	28	9	16	1	25	17	7	0	37
	36	45	29	1	70	5	2	17	73	8
191	0	0	7	0	0	0	4	29	1	0
	0	1	16	11	0	6	48	13	18	0
	57	44	33	9	41	41	28	14	17	0
	18	33	32	4	33	8	10	39	30	88
	15	7	7	31	23	20	2	5	16	2
	10	15	5	45	3	25	8	0	18	10
192	0	0	0	1	14	6	0	5	0	0
	0	0	0	23	18	15	24	22	0	18
	52	0	0	33	28	32	2	33	74	47
	48	0	19	43	15	26	22	27	21	27
	0	35	54	0	25	21	40	10	5	4
	0	65	27	0	0	0	12	3	0	4

	0	1	2	3	4	5	6	7	8	9
193	0	0	11	Ø	0	0	0	0	0	0
	11	40	9	Ø	0	23	2	0	0	36
	42	10	5	Ø	13	23	13	60	39	7
	22	50	19	Ø	26	41	33	40	55	23
	25	0	35	Ø	60	13	34	0	5	12
	0	0	21	Ø	1	0	18	0	1	22
194	0	0	0	0	0	0	1	0	0	0
	32	12	1	0	23	0	33	0	0	26
	9	29	27	0	24	0	17	0	22	21
	23	36	58	84	29	33	11	49	39	9
	14	14	14	16	24	54	8	51	25	44
	22	9	0	0	0	13	30	0	14	0
195	0	0	0	0	0	0	11	0	6	0
	7	26	30	0	20	0	0	0	23	0
	11	20	43	0	35	0	32	31	39	16
	25	24	12	21	31	98	18	33	28	38
	41	8	15	51	14	0	39	36	0	31
	16	22	0	28	0	2	0	0	4	15
196	14	0	0	0	Ø	0	0	0	9	0
	33	0	0	16	Ø	2	3	2	12	0
	18	38	56	12	Ø	55	45	44	29	0
	21	57	17	7	Ø	13	19	42	24	55
	14	5	3	4	Ø	30	24	12	12	28
	0	0	24	61	Ø	0	9	0	14	17
197	0	0	Ø	0	3	0				
	19	0	Ø	0	43	38				
	24	3	Ø	0	8	39				
	42	46	Ø	28	25	12				
	3	35	Ø	62	7	11				
	12	16	Ø	10	14	0				

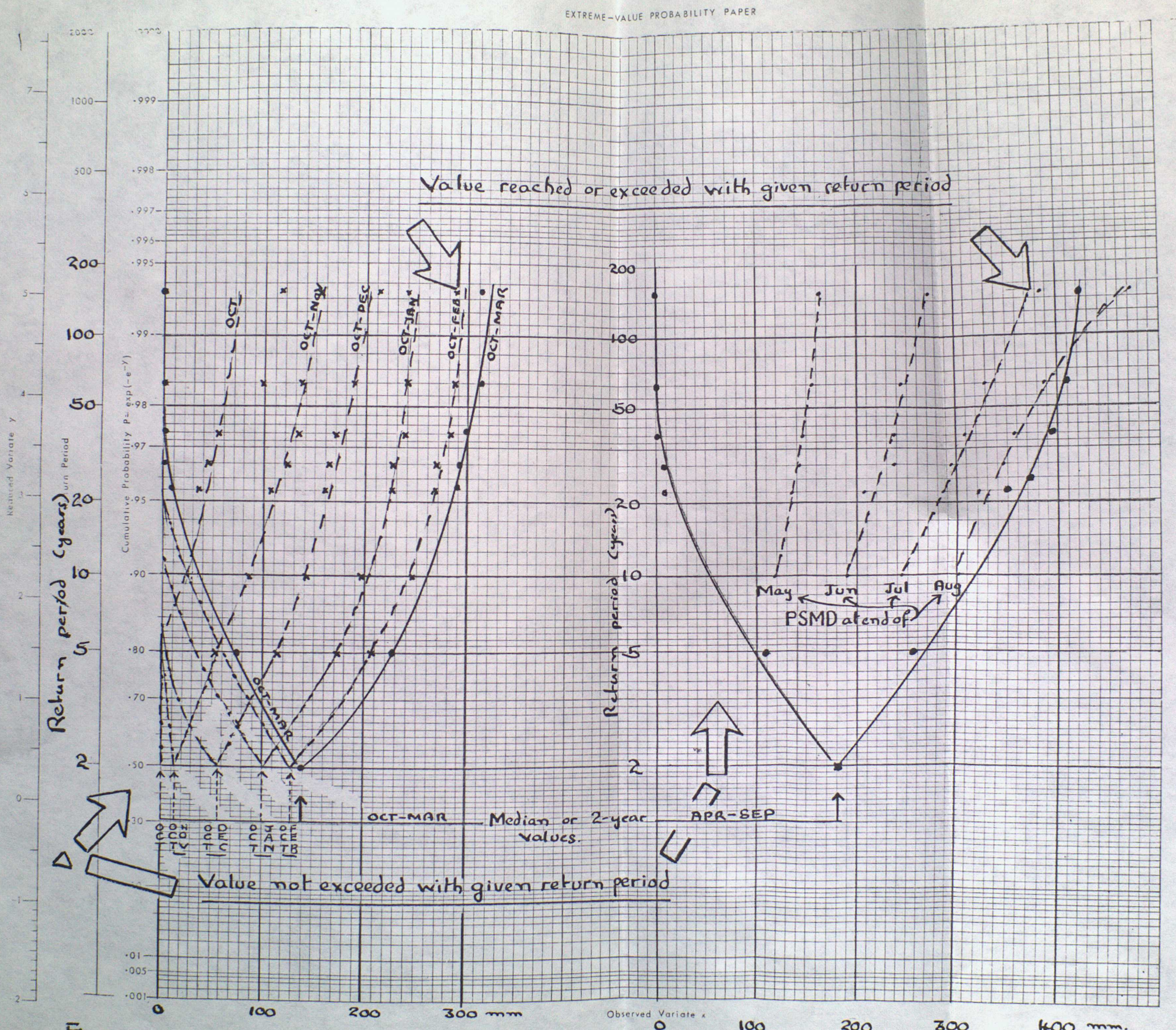

Fig. 1. October to March Hyd. Effective Rainfall on grassland at Kew.

End-of-September Potential Soil Moisture Deficit at Kew ———
End of May, Jun, Jul and Aug PSMD - - - -

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Prepared and drawn in the Cartographic Section, Met.O.13d, Bracknell   Met. O./Carto./D.O./Form File 161

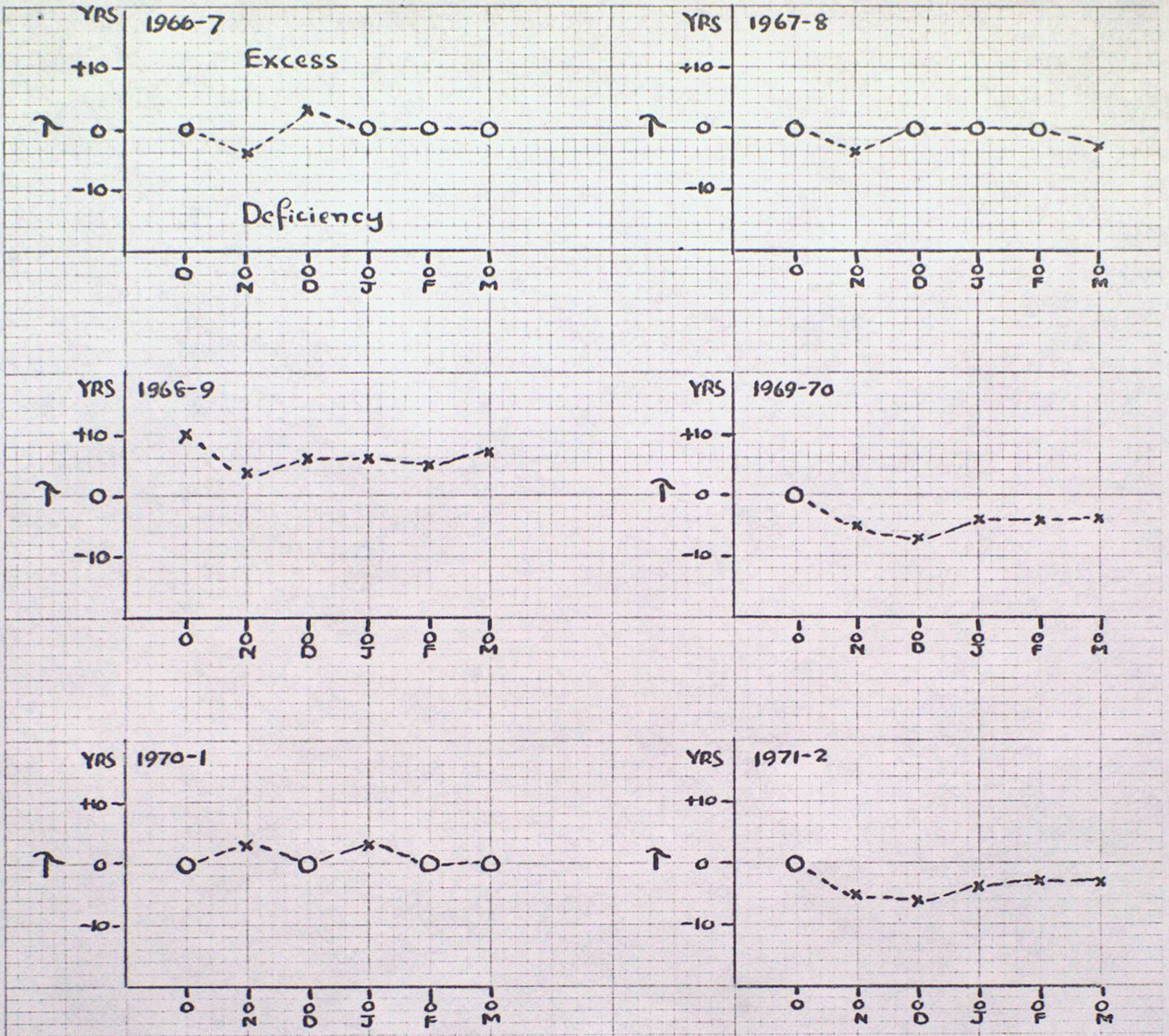

Fig. 2. Return period (τ) of Oct, Oct-Nov, ---, Oct-Mar hydrologically effective rainfall on grass land at Kew for the winters of 1976-7 to 1975-6.

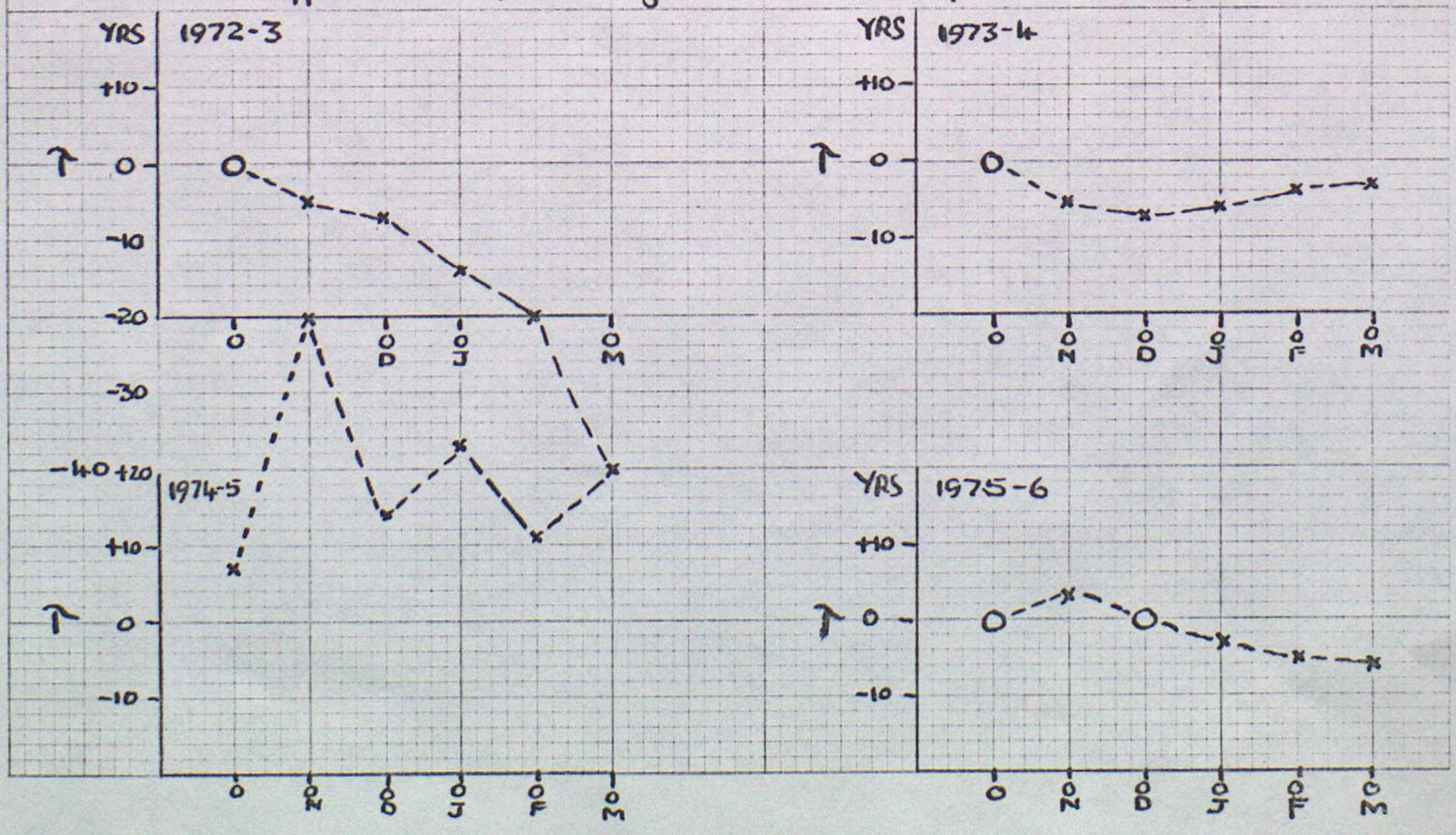

Fig. 3. Percentage of occasions from 1871-1975 at Kew when a given winter month had ≤ a given percentage of that winter's hydrologically effective rainfall on grassland.

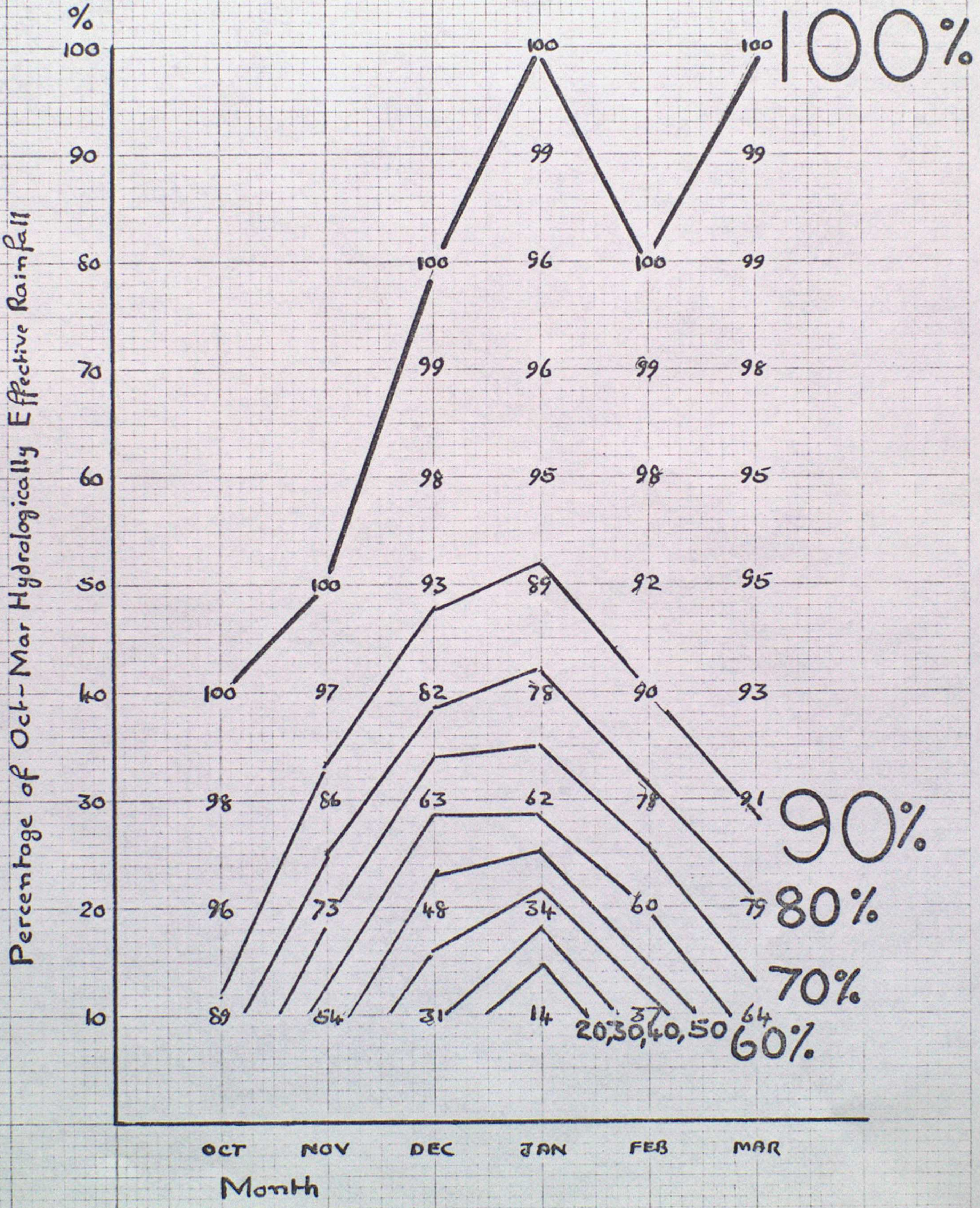

Fig. 4 Percentage of occasions from 1871 to 1875 at Kew when a given pair of winter months had ≤ a given percentage of that winter's hydrologically effective rainfall on grassland.

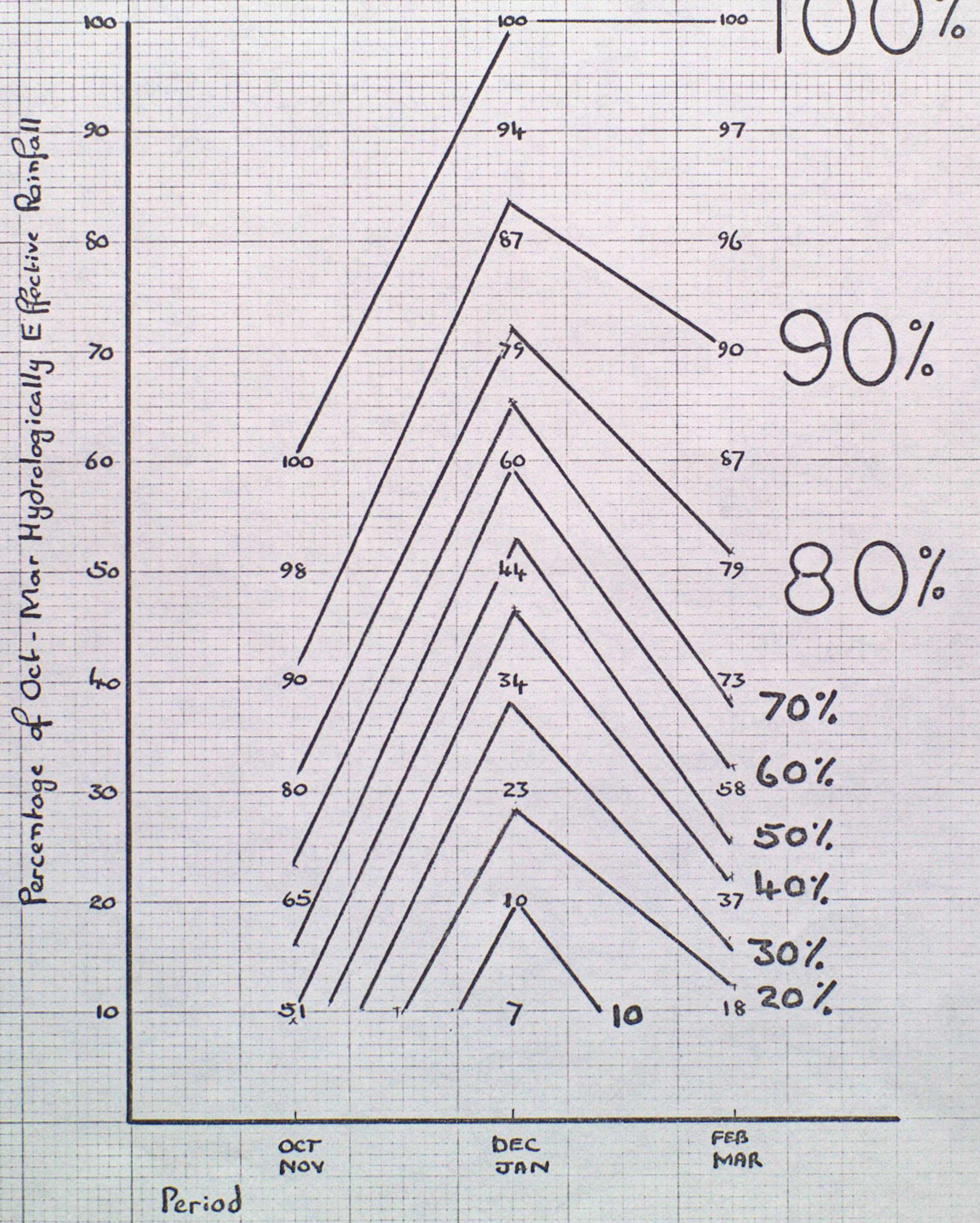

Table 4. 2-month grassland HER at Kew as % of Oct-Mar totals (mm)

	0	1	2	3	4	5	6	7	8	9
187		0	23	4	12	35	0	7	28	15
		90	63	63	76	24	81	67	36	30
		10	14	33	12	41	19	26	36	55
188	43	29	32	11	0	43	0	0	35	10
	29	54	38	53	0	52	88	46	34	68
	28	17	30	36	100	5	12	54	31	22
189	ø	46	47	0	44	33	14	0	0	12
	ø	41	27	73	56	38	46	0	70	52
	ø	13	26	27	0	29	40	100	30	36
190	0	0	0	52	0	0	30	7	0	0
	64	27	62	31	29	70	51	69	27	55
	36	73	38	17	71	30	19	24	73	45
191	0	1	23	11	0	6	52	42	19	0
	75	77	65	13	74	49	38	53	47	88
	25	22	12	76	26	45	10	5	34	12
192	0	0	0	24	32	21	24	27	0	18
	100	0	19	76	43	58	24	60	95	74
	0	100	81	0	25	21	52	13	5	8
193	11	40	20	ø	0	23	2	0	0	36
	64	60	24	ø	39	64	46	100	94	30
	25	0	56	ø	61	13	52	0	6	34
194	32	12	1	0	23	0	34	0	0	26
	32	65	85	84	53	33	28	49	61	30
	36	23	14	16	24	67	38	51	39	44
195	7	26	30	0	20	0	11	0	29	0
	36	44	55	21	66	98	50	64	67	54
	57	30	15	79	14	2	39	36	4	46
196	47	0	0	16	ø	2	3	2	21	0
	39	95	73	19	ø	68	64	86	53	55
	14	5	27	65	ø	30	33	12	26	45
197	19	0	ø	0	46	38				
	66	49	ø	28	33	51				
	15	51	ø	72	21	11				

Table 5

End of September Potential Soil Moisture Deficit at Kew. mm.
1871-1976

	0	1	2	3	4	5	6	7	8	9
187		110	200	195	231	152	226	146	18	0
188	103	178	178	177	240	158	189	239	47	97
189	90	115	125	372	107	220	209	213	289	317
190	268	291	78	1	226	157	279	133	169	121
191	165	343	81	197	226	99	121	24	47	223
192	55	395	178	200	36	140	169	1	197	317
193	113	24	155	287	289	173	145	149	312	204
194	296	39	231	298	256	196	9	281	217	349
195	130	185	170	153	81	256	91	227	30	423
196	186	266	206	184	196	135	137	141	9	204
197	234	120	335	186	187	250	409			

Table 6. 106 Values ranked.

	0	1	2	3	4	5	6	7	8	9
0		423	409	395	372	349	343	335	317	317
1	312	298	296	291	289	289	287	281	279	268
2	266	256	256	250	240	239	234	231	231	227
3	226	226	226	223	220	217	213	209	206	204
4	204	200	200	197	197	196	196	195	189	187
5	186	186	185	184	178	178	178	177	173	170
6	169	169	165	158	157	155	153	152	149	146
7	145	141	140	137	135	133	130	125	121	121
8	120	115	113	110	107	103	99	97	91	90
9	81	81	78	55	47	47	39	36	30	24
10	24	18	9	9	1	1	0			