NEW ZEALAND METEOROLOGICAL SERVICE

TECHNICAL NOTE 223

AIR POLLUTION METEOROLOGY OF THE LOWER HUTT VALLEY, WELLINGTON

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Abstract

Earlier work on the meteorological conditions affecting the dispersal of atmospheric pollution from sites in the southeastern Hutt Valley is reviewed, and further relevant data and comments are presented.

There is a relatively high frequency of light winds in the area. Observations with pilot balloons reveal a tendency for low-level winds, and consequently the drift of pollution, to be channelled along well-defined paths parallelling the eastern hills, especially in stable conditions. Some pollution computations incorporating these effects are included.

The circulation of air in the area under stable, anticyclonic conditions is discussed, and measurements of the associated inversion layers by conventional means and by acoustic radar are described. The implications for the dispersion of pollution are examined.

Introduction

The dispersal of pollution by the atmosphere is very highly dependent on both the wind and the temperature stratification. It is also dependent on the effective height of release of the pollutants. Generally speaking, good dispersion is favoured by increased winds, higher discharge heights and increasingly unstable temperature stratification. Winds, and temperature stratification, are dependent not only on the broad-scale meteorological situation but on local solar and terrestrial radiation, time of day and on the local topography.

The qualitative behaviour of effluent discharged from a stack under various meteorological conditions has been the subject of rather frequent discussions in the literature (see, for example, Bierly and Hewson, 1962).

Over open country it is possible to calculate the expected ground-level concentration of pollution for the normal types of plume behaviour to a tolerable degree of accuracy, using experimentally-determined coefficients appropriate to the prevailing meteorological conditions. However where rising ground or other complicating geographical factors are present the computations become more difficult and less reliable. The site in question comes into this category.

Under certain conditions, different types of plume behaviour are possible which can increase the ground-level concentration of pollution by perhaps an order of magnitude over that expected as above for "normal" plume behaviour. These include aerodynamic downwash of the plume due to buildings, hills etc. near the stack; "looping", where the axis of the plume in typically warm daytime conditions assumes a changing serpentine shape which may intersect the ground for brief periods; and "fumigation". The latter may occur if pollutant is released in a stable inversion layer (i.e. a layer of air in which temperature increases with height rather than decreasing). As convection (and hence dispersion) in such a layer is heavily suppressed a high concentration builds up downwind at the height of release. If, subsequently, solar heating causes mixing of the air up to this height, trapped pollutant may be brought down to ground level in appreciable concentrations. This effect may be amplified if there are lateral boundaries to dispersion, such as would occur in a valley.

In discussing the dispersal of pollutants from a specific site one has to look at the meteorological conditions from two different viewpoints. First one has to be concerned with the general climatology of the area, to assess the mean pattern of ground-level pollution and the broader-scale, longer-term effects. Secondly, one must consider in some detail those meteorological situations where dispersion is likely to be especially poor. Such situations may or may not contribute significantly to the mean pollution patterns depending on their frequency of occurrence, but the pollution concentrations reached during them may be important if they are likely to affect populated or ecologically significant areas.

Standard long-term climatological information, of the type routinely provided for N.Z. Meteorological Service stations, forms the basis for this type of study, but it is generally necessary to supplement it with additional, specialised observations of air trajectories and temperature stratifications, especially under the conditions giving poor dispersion of pollutants.

Previous Studies

Certain earlier reports and observational material are directly relevant to the present case.

Gabites, in 1962, made a survey of the general pattern of air pollution to be expected from a source in the vicinity of Point Howard, some 1.8 km from the Hutt River mouth, based mainly on climatological and wind records from Gracefield. This study was stimulated by a proposal to construct a fertilizer works on the then-planned Seaview reclamation.

Gabites showed that in spite of Wellington's reputation for windiness the frequency of occurrence of calm, poor dispersion conditions during the night hours was just as great at Gracefield as at many other New Zealand localities where pollution was already of concern. From observations of smoke-drifts in the area Gabites noted that the winds recorded as calms by the anemometer at Gracefield were often light down-valley drifts at night and in the early morning, and he suggested that these would carry pollution released at Point Howard along the eastern side of the harbour over established residential areas.

From sample calculations made for a representative variety of conditions Gabites computed the approximate yearly mean distribution of pollution for a source emitting continuously at Point Howard. The computed patterns are shown in Fig. 1. It should be noted that in these computations a source height of 50 m was used, and that Gabites' conclusions regarding the drift and dispersal of pollutants were only intended to apply to emissions up to this height range.

In his paper, Gabites recommended a closer study of the light wind drifts in the southeastern Hutt Valley, and in the winters of 1963 and 1964 some 75 low-level pilot balloon flights were made from the Seaview area. The results of this work will be discussed in more detail in the appropriate section below, but it might be mentioned here that low-level winds in stable conditions tend to be channelled in directions parallelling the eastern sides of the Hutt Valley and Wellington Harbour.

In an unpublished report on this work, Kidson described computations of mean ground-level pollution patterns from a source at Seaview, using the observed trajectories in combination with the Gracefield anemometer records. From plots of the balloon trajectories Kidson derived relationships between the probabilities of trajectories originating at Seaview crossing the various squares of a rectangular grid superimposed on the area, and the anemometer wind directions. These probabilities were in turn combined with the climatological probabilities of the various windspeed and

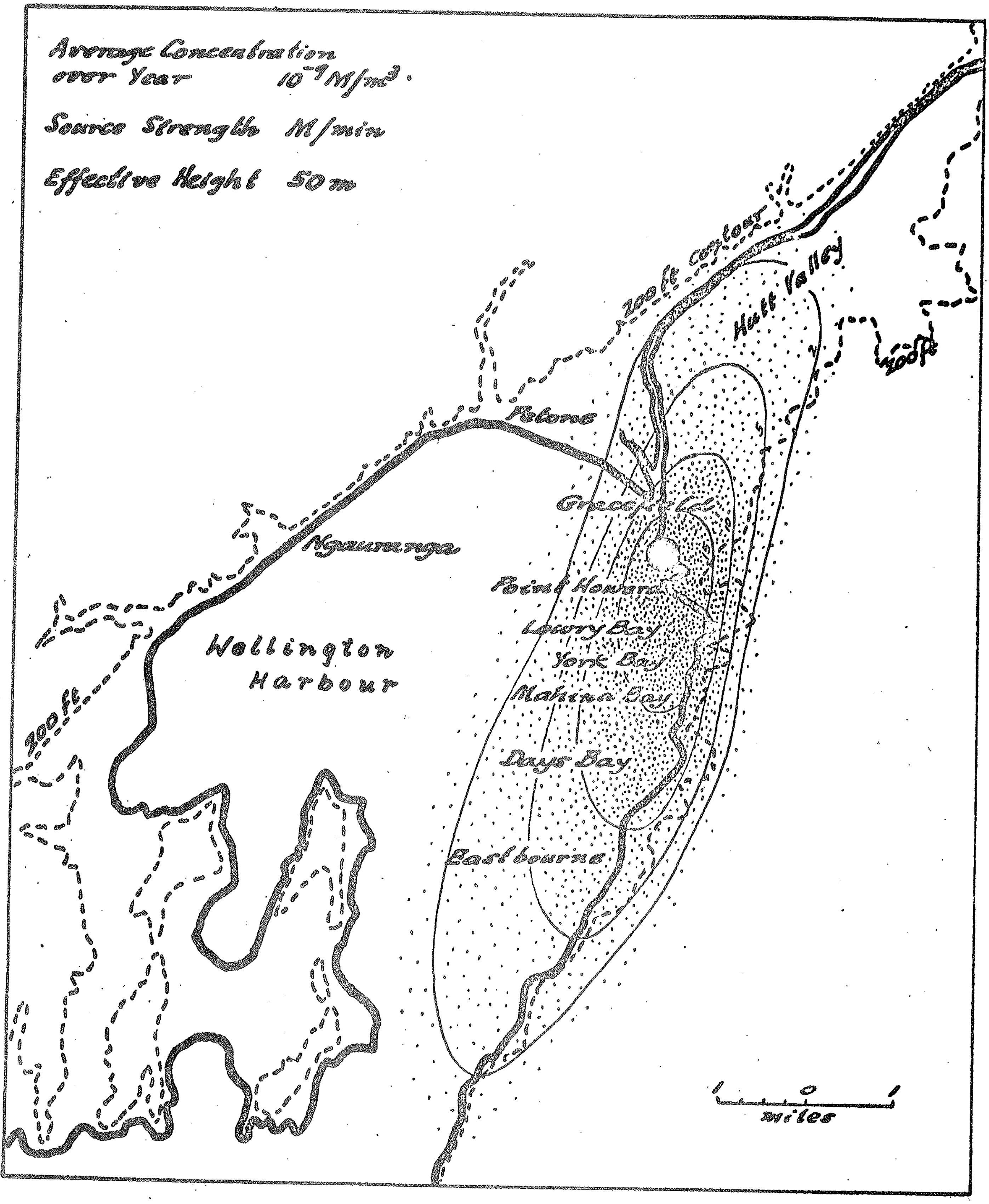

Fig. 1 Approximate pattern of ground level pollution expected from source near Point Howard. (after Gabites)

direction groupings as obtained by analysis of the Gracefield anemometer records, and the results used as a basis for the computation of mean ground-level pollution in each grid square. The latter was accomplished by using an appropriately integrated form of Sutton's well-known diffusion equation (Sutton,1953). The parameters used in Sutton's equation were chosen as functions of the windspeed categories used, independent of direction, and were intended to represent yearly means appropriate to the times of day under consideration.

The results of Kidson's computations for four representative times of day are shown in Fig. 2. Compared with Gabites' results the pattern of ground-level pollution is somewhat altered in shape, and narrower, reflecting the tendency for the air trajectories to be "channelled" by the eastern topography. The concentrations on the axes of the patterns tend to be somewhat higher, about double Gabites' values even without allowing for the fact that Kidson's computations were for a source height of 60 m compared with Gabites' 50 m. Such higher concentrations would be expected because of the channelling effect but one should avoid placing too much weight on the absolute values or their ratios as in both sets of computations a number of unsubstantiated assumptions and approximations were necessarily included.

As balloon ascents were only available for the daylight hours Kidson did not attempt computations for the night-time, when in general poorer dispersion conditions might be expected. Some indication of the trend can be had by considering his results for 0900 N.Z.S.T. where peak concentrations occur further away from the source and the rate of decrease with distance is less than for midday.

Neither of the above studies considers the dispersion of pollutants in strong inversion conditions, as might occur at night during anticyclonic conditions. In such conditions it would be crucial whether or not the pollution were emitted at an effective height above or below the top of the inversion layer.

At the time of the Seaview studies only three direct measurements of the low-level temperature gradient were made. These were described in an unpublished note by Kidson in 1964. Only one sounding, at 0900 N.Z.S.T. on 10 July, sampled the early-morning inversion. This showed a distinct inversion layer from 33 m up to the maximum height of measurement (160 m), with a temperature difference of some 2°C over that height range. The third sounding, at 1100 N.Z.S.T. on 18 August, showed an inversion layer above 130 m. On both these occasions smoke from domestic and industrial sources was observed trapped below the inversion layer.

Further discussion of inversion conditions will be found in a later section.

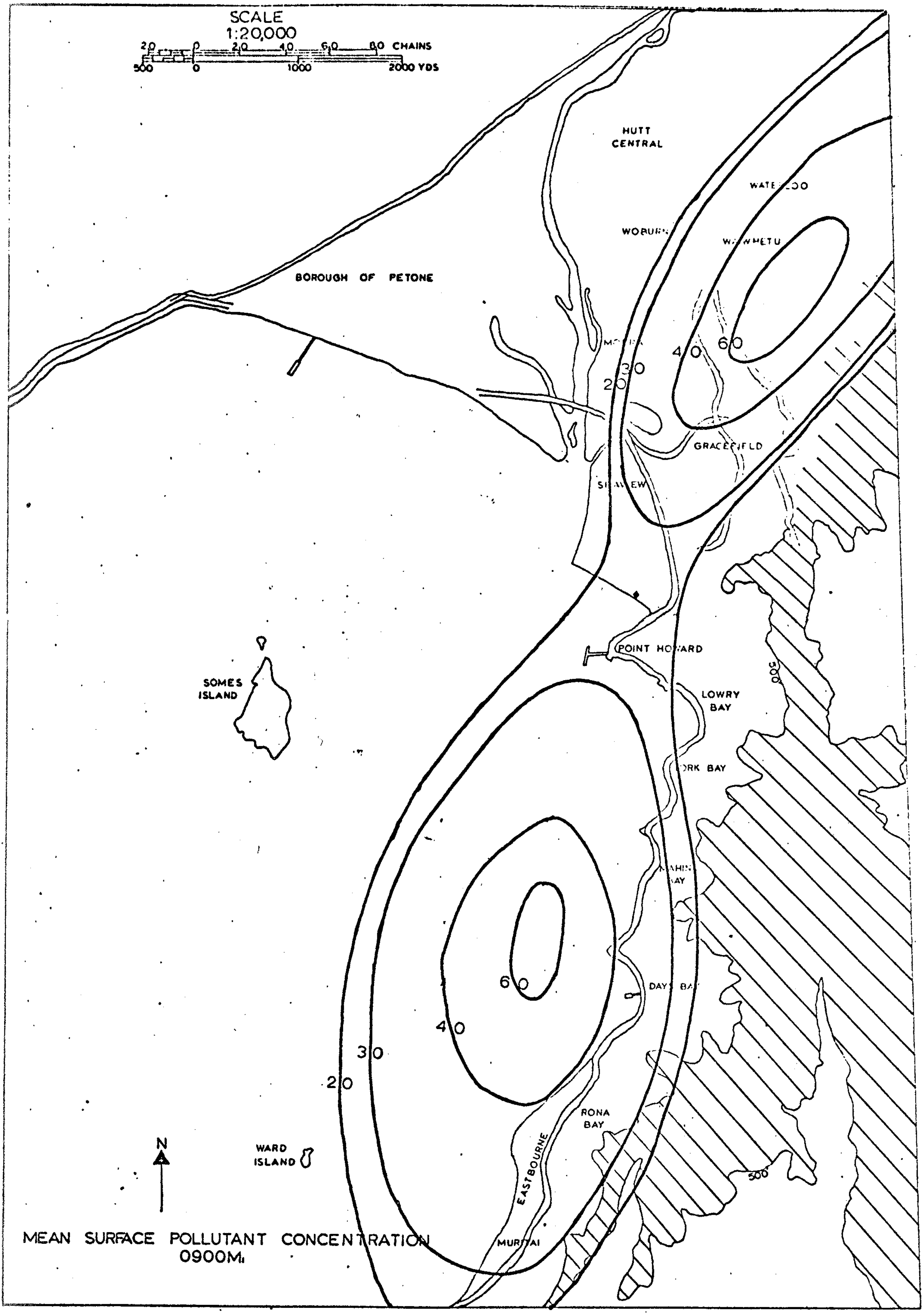

Fig. 2(a) Mean surface pollutant concentration 0900 N.Z.S.T.

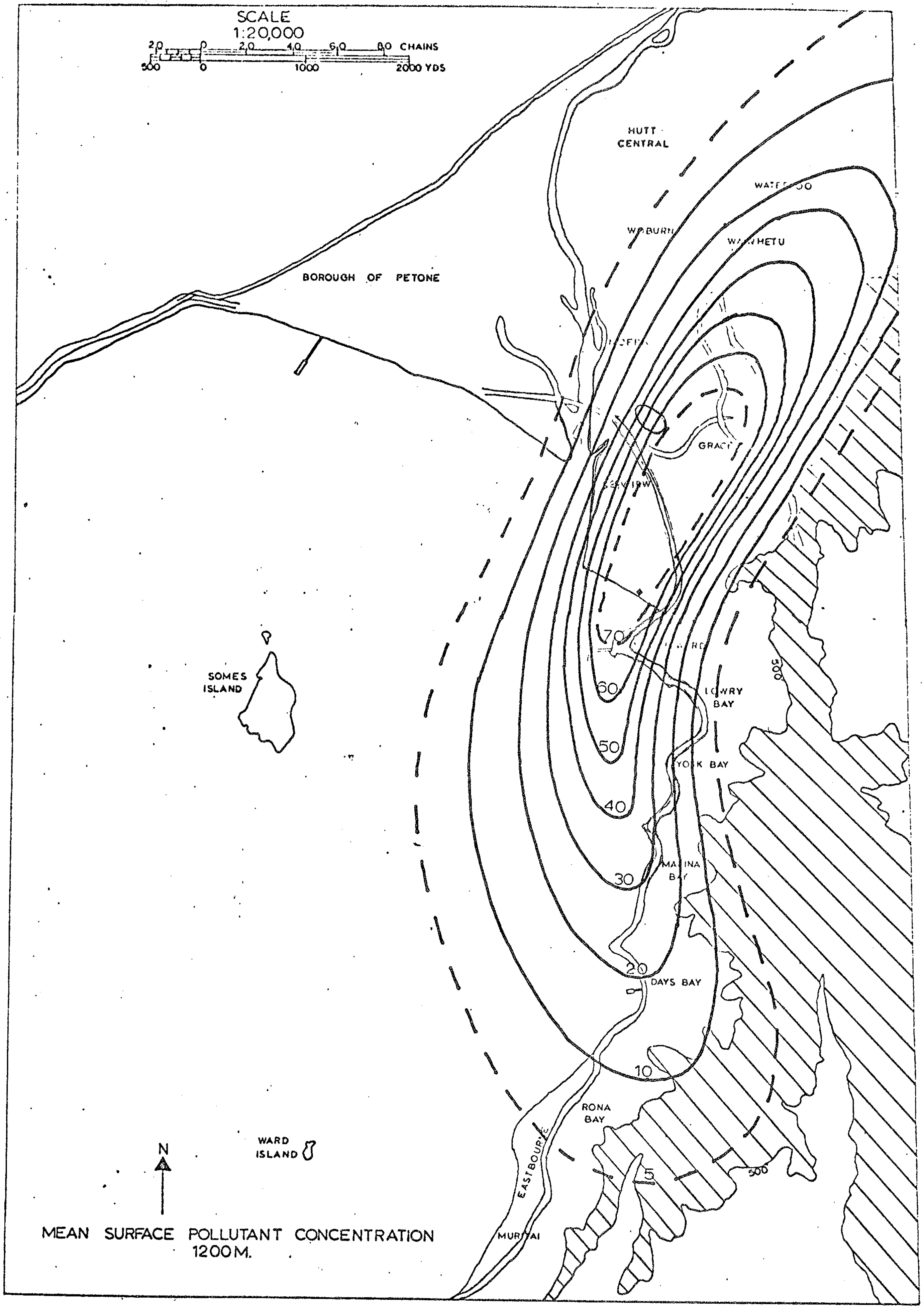

Fig. 2(b) Mean surface pollutant concentration 1200 N.Z.S.T.

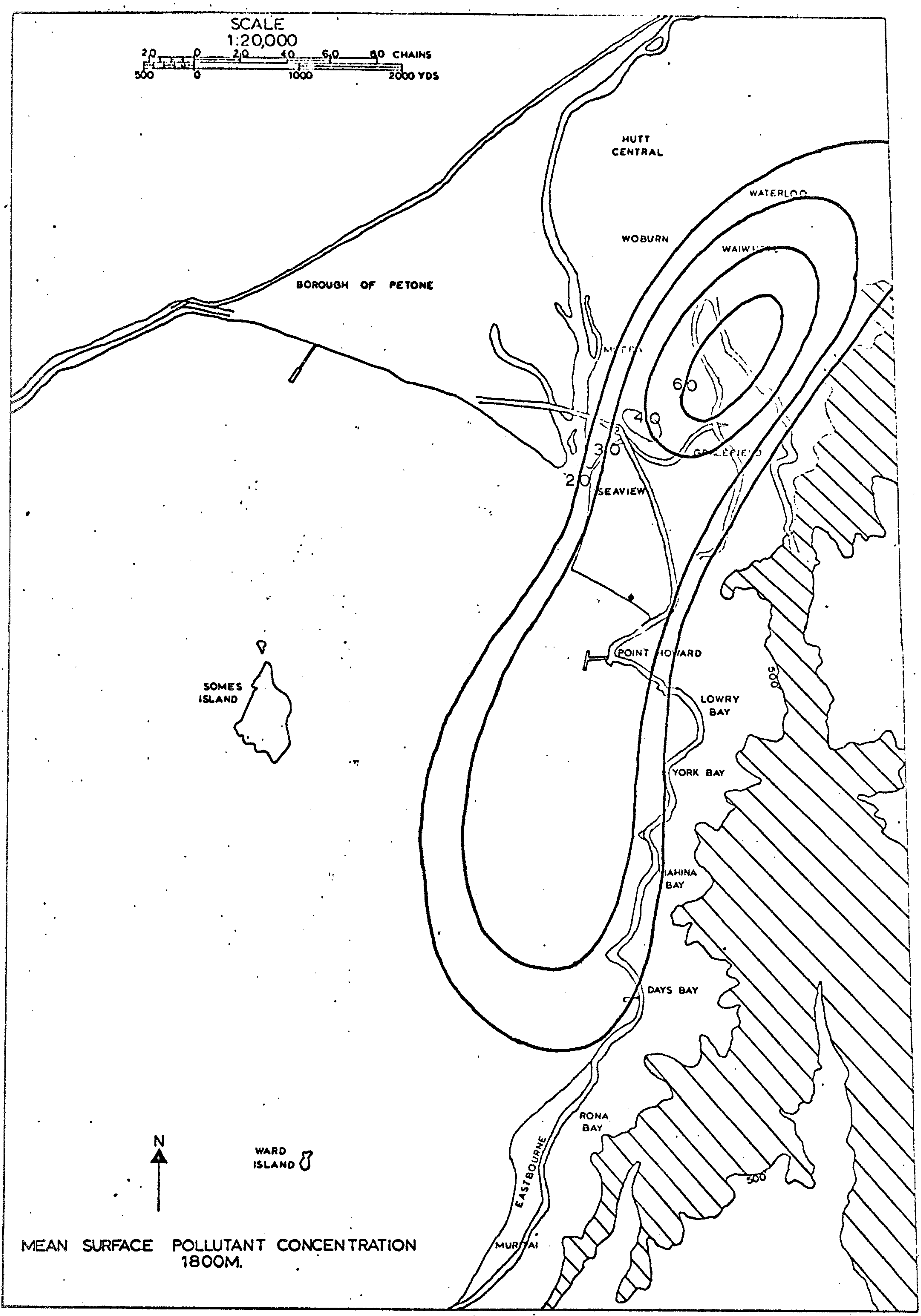

Fig. 2(c) Mean surface pollutant concentration 1800 N.Z.S.T.

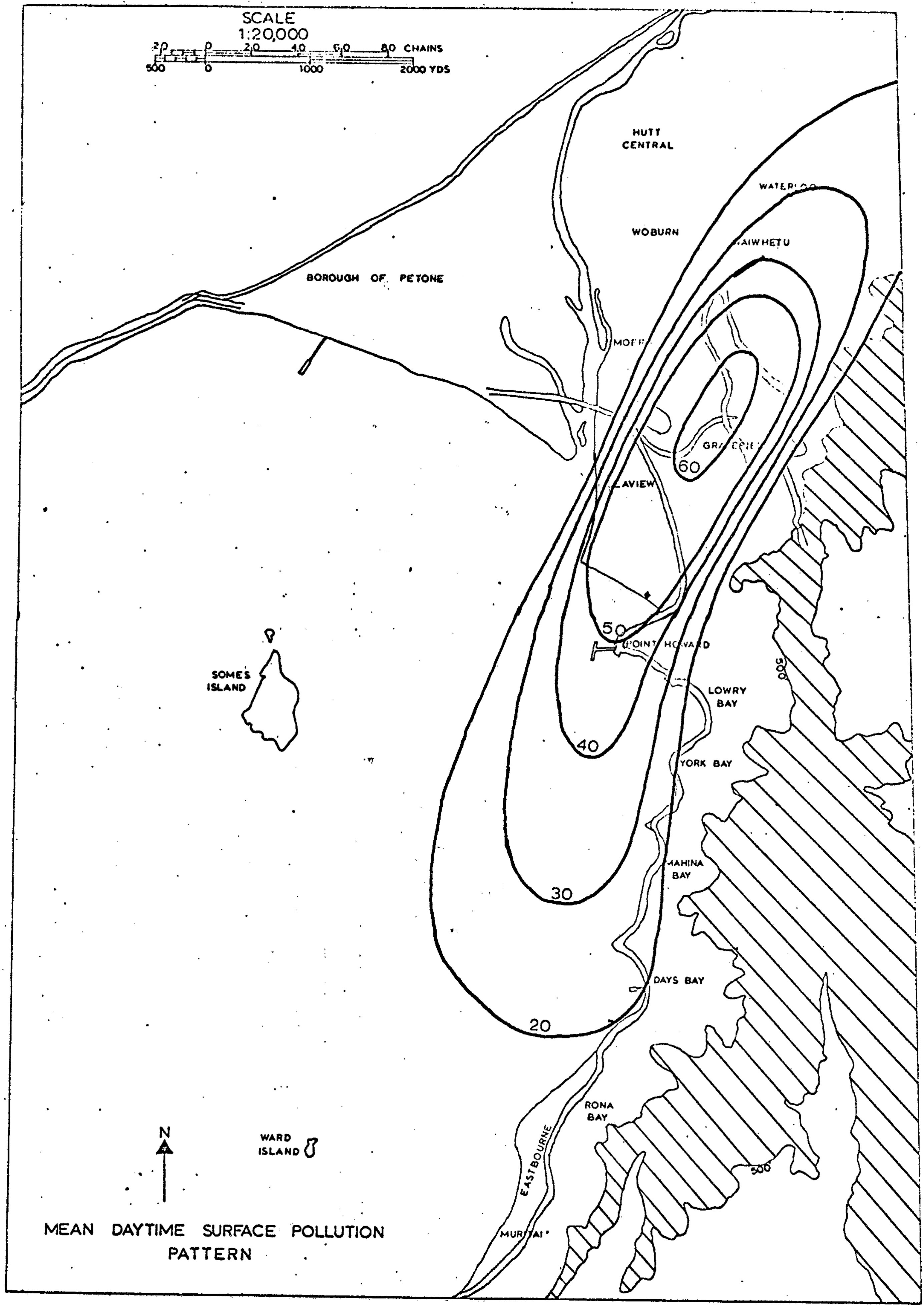

Fig. 2(d) Mean daytime surface pollution pattern.

Surface Winds

Probably the most nearly representative series of wind measurements is that from the Dines anemograph at the Physics and Engineering Laboratory, D.S.I.R., Gracefield, installed October 1960. Both Gabites' and Kidson's reports referred to above were based on these measurements. Approximately a four year period has been punched on to cards and analysed by machine.

Tables showing the wind frequency distribution at Gracefield for the year and for the winter and spring are given in Table 1. The prevailing wind direction is northerly to northeasterly. Winds from this direction have nearly twice the frequency, taken over a year, than those from the other predominant direction grouping - south to southwest. There are significant changes in the average wind conditions, depending on the season and time of day. For example in winter, southerlies are nearly as common as northerlies, and the frequency of calm or light winds is very much greater overnight and in the early morning than midday and early afternoon.

Closer consideration of these tables also shows that there is a marked increase in the frequency of northeasterly winds overnight and during the morning, compared with the afternoons. These winds are generally in the 1-7 m/s range and are associated with the valley circulation (see below). On the other hand, winds from a more northerly quarter, while still relatively frequent overnight, tend to be more frequent during the day and to blow with increased speed.

A similar examination of the winds from the southerly quarter shows that light southwesterlies are common from late morning to late afternoon, more especially in the summer months but even in the winter. Southwesterlies are infrequent during the night hours, as wind from this direction is frequently associated with sea breeze effects. Winds from a more southerly direction show little diurnal variation in frequency and, like the northerlies mentioned above, are the product of the large-scale synoptic situation rather than local thermal effects.

Figure 3 shows the percentage of winds less than or equal to specified values as functions of the time of day, in the different seasons. Generally, winds tend to be strongest in Spring and lightest in Autumn and Winter. As noted by Gabites the frequency of light winds (say under 2 m/s), in which dispersion of pollutants is likely to be poor, is rather high considering the reputation of the Wellington area for windiness. Most of

Table 1(a) Wind frequency distribution, Gracefield, October 1960 - June 1962 and April 1963 - August 1964.

0300 CALM 163

	N	NE	E	SE	S	SW	W	NW	
01-04	122	90	29	31	73	5	3		353
05-09	87	141	7		75	6		1	317
10-14	73	65			25	7		1	171
15-19	26	19			11	4			60
20-24	3	2			5				10
25-									
	311	317	36	31	189	22	3	2	

NR. OBS 1074

0600 CALM 164

	N	NE	E	SE	S	SW	W	NW	
01-04	138	85	24	29	59	4	1	5	345
05-09	74	153	3	2	65	12	1	2	312
10-14	57	77	1		36	7			178
15-19	26	21		1	11	3			62
20-24	4	3			5				12
25-		1			4				5
	299	340	28	32	180	26	2	7	

NR. OBS 1078

0900 CALM 116

	N	NE	E	SE	S	SW	W	NW	
01-04	117	59	12	5	79	41		7	320
05-09	85	103	5	1	76	32		2	304
10-14	99	84	1		37	10			231
15-19	39	23	1		17	5		1	86
20-24	7	3			3	1			14
25-	1				3				4
	348	272	19	6	215	89		10	

NR. OBS 1075

1200 CALM 21

	N	NE	E	SE	S	SW	W	NW	
01-04	62	13	2	1	37	90	10	6	221
05-09	128	31			69	106	6	17	357
10-14	181	41			39	63		2	326
15-19	91	30			19	13			153
20-24	11	3			6	6			26
25-	2				4				6
	475	118	2	1	174	278	16	25	

NR. OBS 1110

1500 CALM 9

	N	NE	E	SE	S	SW	W	NW	
01-04	36	10	2	1	37	77	6	7	176
05-09	133	24	2	2	84	127	2	24	398
10-14	185	38			44	57			324
15-19	103	20			20	18			161
20-24	15	2			5	3			25
25-	2	1			1	2			6
	474	95	4	3	191	284	8	31	

NR. OBS 1099

1800 CALM 39

	N	NE	E	SE	S	SW	W	NW	
01-04	38	56	36	29	87	56	7	5	314
05-09	114	104	9		97	56		5	385
10-14	132	52			34	20			238
15-19	56	25			17	5			103
20-24	7	3			4	1			15
25-					1			1	2
	347	240	45	29	240	138	7	11	

NR. OBS 1096

2100 CALM 119

	N	NE	E	SE	S	SW	W	NW	
01-04	81	93	57	30	84	18	3	2	368
05-09	92	166	20		60	14	2	1	355
10-14	68	71	1		29	6			175
15-19	27	14	1		9	3			54
20-24	4	1			4	1			10
25-		1				1			2
	272	346	79	30	186	43	5	3	

NR. OBS 1083

2400 CALM 150

	N	NE	E	SE	S	SW	W	NW	
01-04	111	98	31	34	62	9	3	1	349
05-09	78	170	9		59	22	1	1	340
10-14	85	65			24	5			179
15-19	31	9			9	3			52
20-24	2	2			3	1			8
25-					1				1
	307	344	40	34	158	40	4	2	

NR. OBS 1079

Table 1(b) Wind frequency distribution, Gracefield: Spring.

0300 CALM 22

	N	NE	E	SE	S	SW	W	NW	
01-04	19	19	5	8	17				68
05-09	20	35	3		16	2			76
10-14	17	23			5	1			46
15-19	7	5			2				14
20-24	1				1				2
25-									
	64	82	8	8	41	3			

NR. OBS 228

0600 CALM 30

	N	NE	E	SE	S	SW.	W	NW	
01-04	16	22	5	4	17	1			65
05-09	9	42			10	2	1		64
10-14	7	30			6	2			45
15-19	10	3		1	4				18
20-24	2	2							4
25-					1				1
	44	99	5	5	38	5	1		

NR. OBS 227

0900 CALM 15

	N	NE	E	SE	S	SW	W	NW	
01-04	11	14		1	12	12		1	51
05-09	17	24	2		11	9		1	64
10-14	28	25	1		10	3			67
15-19	13	7			3	1			24
20-24	3	1			1				5
25-					1				1
	72	71	3	1	38	25		2	

NR. OBS 227

1200 CALM

	N	NE	E	SE	S	SW	W	NW	
01-04	3	3	1		4	15	1		27
05-09	25	4			11	27		3	70
10-14	53	5			5	15			78
15-19	30	11			4	3			48
20-24	6				2	2			10
25-	1				2				3
	118	23	1		28	62	1	3	

NR. OBS 236

1500 CALM

	N	NE	E	SE	S	SW	W	NW	
01-04	6	2		1	5	12	1	2	29
05-09	27	1	1		16	25		1	71
10-14	43	8			8	16			75
15-19	32	7			3	4			46
20-24	7	1				1			9
25-	1	1				2			4
	116	20	1	1	32	60	1	3	

NR. OBS 234

1800 CALM 4

	N	NE	E	SE	S	SW	W	NW	
01-04	10	7	2		9	17	2	1	48
05-09	23	16	1		19	22		1	82
10-14	34	12			6	6			58
15-19	16	15			4	2			37
20-24	2	1			2				5
25-									
	85	51	3		40	47	2	2	

NR. OBS 234

2100 CALM 14

	N	NE	E	SE	S	SW	W	NW	
01-04	10	27	15	10	14	6	1		83
05-09	9	41	3		7	2	1		63
10-14	19	24			8				51
15-19	11	3			2	1			17
20-24	1				2				3
25-									
	50	95	18	10	33	9	2		

NR. OBS 231

2400 CALM 18

	N	NE	E	SE	S	SW	W	NW	
01-04	21	26	8	6	12	2	1		76
05-09	10	49	2		8	5			74
10-14	19	21			6	1			47
15-19	10	2			3				15
20-24									
25-					1				1
	60	98	10	6	30	8	1		

NR. OBS 231

Table 1(c) Wind frequency distribution, Gracefield: Summer.

0300 CALM 44

	N	NE	E	SE	S	SW	W	NW	
01-04	27	28	9	4	18	2	1		89
05-09	19	41	1		13				74
10-14	16	16			5	1			38
15-19	6	2			1	1			10
20-24	2	2			1				5
25-									
	70	89	10	4	38	4	1		

NR. OBS 260

0600 CALM 34

	N	NE	E	SE	S	SW	W	NW	
01-04	37	30	6	10	18			1	102
05-09	14	37	1		11	3			66
10-14	15	20			6	1			42
15-19	5	6			4				15
20-24	1								1
25-		1			1				2
	72	94	7	10	40	4		1	

NR. OBS 262

0900 CALM 11

	N	NE	E	SE	S	SW	W	NW	
01-04	21	13	2	1	23	19		3	82
05-09	24	16			16	12		1	69
10-14	39	24			8	4			75
15-19	9	8			3	1			21
20-24	3								3
25-					1				1
	96	61	2	1	51	36		4	

NR. OBS 262

1200 CALM

	N	NE	E	SE	S	SW	W	NW	
01-04	8				8	18		1	35
05-09	37	1			10	32	1	6	87
10-14	54	8			8	22		1	93
15-19	31	7			5	3			46
20-24		1			2				3
25-									
	130	17			33	75	1	8	

NR. OBS 264

1500 CALM

	N	NE	E	SE	S	SW	W	NW	
01-04	3		1		6	16	1		27
05-09	36	3			15	28		9	91
10-14	56	12			8	17			93
15-19	32	4			5	7			48
20-24	2				1	1			4
25-	1								1
	130	19	1		35	69	1	9	

NR. OBS 264

1800 CALM 1

	N	NE	E	SE	S	SW	W	NW	
01-04	11				10	22	4	2	49
05-09	57	10			25	17		3	112
10-14	46	7			6	12			71
15-19	21	4			2	1			28
20-24	2								2
25-									
	137	21			43	52	4	5	

NR. OBS 263

2100 CALM 16

	N	NE	E	SE	S	SW	W	NW	
01-04	10	28	12	8	25	7	1		91
05-09	29	51	9		14	4			107
10-14	14	17			4	3			38
15-19	4	4	1						9
20-24	1								1
25-									
	58	100	22	8	43	14	1		

NR. OBS 262

2400 CALM 38

	N	NE	E	SE	S	SW	W	NW	
01-04	19	25	9	7	18	2			80
05-09	19	47	6		12	4			88
10-14	21	18			2	2			43
15-19	7	2			1				10
20-24	1	1							2
25-									
	67	93	15	7	33	8			

NR. OBS 261

Table 1(d) Wind frequency distribution, Gracefield: Autumn.

0300 CALM 51

	N	NE	E	SE	S	SW	W	NW	
01-04	44	23	9	7	16				99
05-09	20	33	1		26	1		1	82
10-14	24	20			8	1			53
15-19	8	9			3				20
20-24									
25-									
	96	85	10	7	53	2		1	

NR. OBS 305

0600 CALM 48

	N	NE	E	SE	S	SW	W	NW	
01-04	48	17	6	8	16	1		2	98
05-09	29	36		1	19	3		1	89
10-14	22	19			12	2			55
15-19	4	10			1				15
20-24	1				1				2
25-									
	104	82	6	9	49	6		3	

NR. OBS 307

0900 CALM 51

	N	NE	E	SE	S	SW	W	NW	
01-04	46	14	5	1	27	7		2	102
05-09	24	29			19	2			74
10-14	21	22			10	1			54
15-19	12	5	1		4				22
20-24		1							1
25-	1								1
	104	71	6	1	60	10		2	

NR. OBS 305

1200 CALM 8

	N	NE	E	SE	S	SW	W	NW	
01-04	25	4	1	1	16	30	4	4	85
05-09	33	8			21	26	2	3	93
10-14	43	15			13	15		1	87
15-19	23	6			3	2			34
20-24	5	1			1	2			9
25-	1								1
	130	34	1	1	54	75	6	8	

NR. OBS 317

1500 CALM 3

	N	NE	E	SE	S	SW	W	NW	
01-04	13	4			11	23		3	54
05-09	37	7	1	2	27	42		9	125
10-14	47	6			13	14			80
15-19	29	5			5	5			44
20-24	6				1				7
25-									
	132	22	1	2	57	84		12	

NR. OBS 313

1800 CALM 17

	N	NE	E	SE	S	SW	W	NW	
01-04	7	21	14	14	34	10		1	101
05-09	23	37	2		32	11			105
10-14	30	22			8	1			61
15-19	15	4			4	1			24
20-24	3	1							4
25-									
	78	85	16	14	78	23		1	

NR. OBS 312

2100 CALM 48

	N	NE	E	SE	S	SW	W	NW	
01-04	26	29	16	6	26	3		1	107
05-09	19	42	4		14				79
10-14	23	22	1		8	2			56
15-19	5	4			2				11
20-24	2	1				1			4
25-		1							1
	75	99	21	6	50	6		1	

NR. OBS 306

2400 CALM 54

	N	NE	E	SE	S	SW	W	NW	
01-04	38	25	6	15	13	3	1		101
05-09	23	34			16	6		1	80
10-14	29	18			4	1			52
15-19	9	3			3	1			16
20-24	1								1
25-									
	100	80	6	15	36	11	1	1	

NR. OBS 304

Table 1(e) Wind frequency distribution, Gracefield: Winter.

0300 CALM 46

	N	NE	E	SE	S	SW	W	NW	
01-04	32	20	6	12	22	3	2		97
05-09	28	32	2		20	3			85
10-14	16	6			7	4		1	34
15-19	5	3			5	3			16
20-24					3				3
25-									
	81	61	8	12	57	13	2	1	

NR. OBS 281

0600 CALM 52

	N	NE	E	SE	S	SW	W	NW	
01-04	37	16	7	7	8	2	1	2	80
05-09	22	38	2	1	25	4		1	93
10-14	13	8	1		12	2			36
15-19	7	2			2	3			14
20-24		1			4				5
25-					2				2
	79	65	10	8	53	11	1	3	

NR. OBS 282

0900 CALM 39

	N	NE	E	SE	S	SW	W	NW	
01-04	39	18	5	2	17	3		1	85
05-09	20	34	3	1	30	9			97
10-14	11	13			9	2			35
15-19	5	3			7	3		1	19
20-24	1	1			2	1			5
25-					1				1
	76	69	8	3	66	18		2	

NR. OBS 281

1200 CALM 13

	N	NE	E	SE	S	SW	W	NW	
01-04	26	6			9	27	5	1	74
05-09	33	18			27	21	3	5	107
10-14	31	13			13	11			68
15-19	7	6			7	5			25
20-24		1			1	2			4
25-					2				2
	97	44			59	66	8	6	

NR. OBS 293

1500 CALM 6

	N	NE	E	SE	S	SW	W	NW	
01-04	14	4	1		15	26	4	2	66
05-09	33	13			26	32	2	5	111
10-14	39	12			15	10			76
15-19	10	4			7	2			23
20-24		1			3	1			5
25-					1				1
	96	34	1		67	71	6	7	

NR. OBS 288

1800 CALM 17

	N	NE	E	SE	S	SW	W	NW	
01-04	10	28	20	15	34	7	1	1	116
05-09	11	41	6		21	6		1	86
10-14	22	11			14	1			48
15-19	4	2			7	1			14
20-24		1			2	1			4
25-					1			1	2
	47	83	26	15	79	16	1	3	

NR. OBS 287

2100 CALM 41

	N	NE	E	SE	S	SW	W	NW	
01-04	35	9	14	6	19	2	1	1	87
05-09	35	32	4		25	8	1	1	106
10-14	12	8			9	1			30
15-19	7	3			5	2			17
20-24					2				2
25-						1			1
	89	52	18	6	60	14	2	2	

NR. OBS 284

2400 CALM 40

	N	NE	E	SE	S	SW	W	NW	
01-04	33	22	8	6	19	2	1	1	92
05-09	26	40	1		23	7	1		98
10-14	16	8			12	1			37
15-19	5	2			2	2			11
20-24		1			3	1			5
25-									
	80	73	9	6	59	13	2	1	

NR. OBS 283

these calms or light winds occur overnight and in the early morning, with the relative frequency of winds under 2 m/s being in excess of 40%. During the day the relative frequency of winds under 2 m/s drops sharply, especially in Spring and Summer. As would be expected, the fraction of the day when light winds are less probable is greater in Summer than in Winter.

It is probable that the frequency of light winds at the Hutt River mouth may be somewhat less than the above analysis shows. The Gracefield anemometer is situated fairly close in to the hills on the eastern side of the Hutt Valley and may receive some sheltering compared with the former site. For comparison we may consider the wind at Wellington Airport, some 14 km to the southwest, and in a more exposed position. At this station the frequency of winds under 2 m/s is only 16% at night and 8% by day. Observation of the drift of smoke suggests that the wind pattern at the Hutt River mouth is more akin to that at Gracefield than to that at the airport, and the frequency of light winds probably lies between the two, but with a bias towards the former.

A further factor which should be mentioned is the relatively short period of data included in the Gracefield analysis, as one or two much calmer than average years could introduce a serious bias. An analysis of data acquired since the above study is being made and should resolve this point although it may be argued that the earlier data are representative of what happened in some years, even if they were not average ones.

Low Level Air Trajectories

Although the surface wind analyses discussed above give considerable information relevant to the dispersal of pollution it is useful to consider in more detail the likely paths taken by the pollutants after emission. To study the general trajectories of air in the southeastern Hutt Valley - Eastern Harbour areas a number of hydrogen or helium-filled balloons have been released and tracked by theodolite. These balloons carried weights, adjusted so as to give a rather low ascent rate, between near-zero and about 0.6 m/s. The tracks of such balloons give some simulation of the trajectories of pollutants in the horizontal plane appropriate to the height of the balloon, but do not closely simulate the vertical motions.

The "low-lift" balloon flights to be described were made some years ago in connection with the proposed fertilizer works at Seaview and were launched from sites on the Seaview reclamation. Pollution calculations based

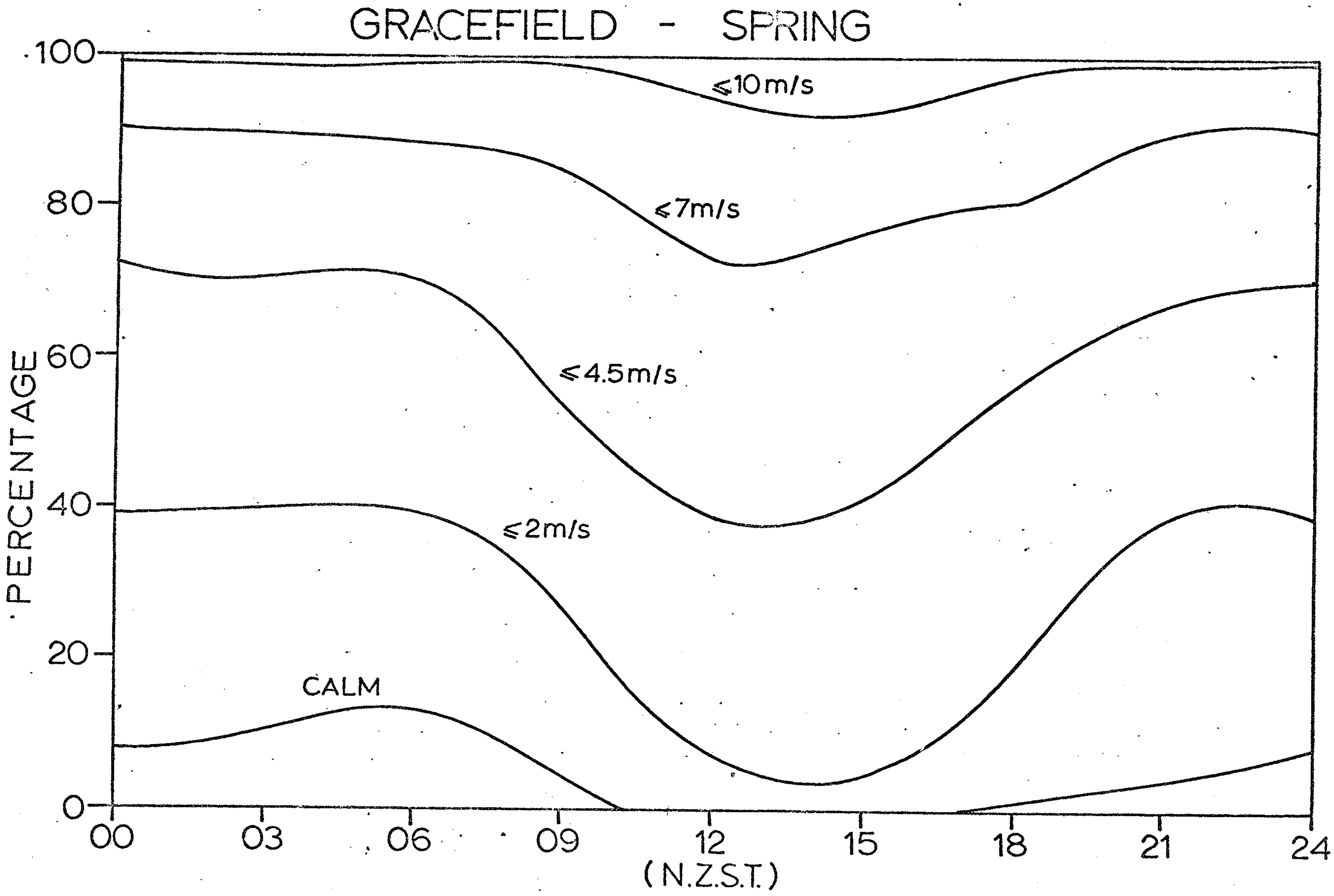

Fig. 3(a) Frequencies of winds less than values specified.

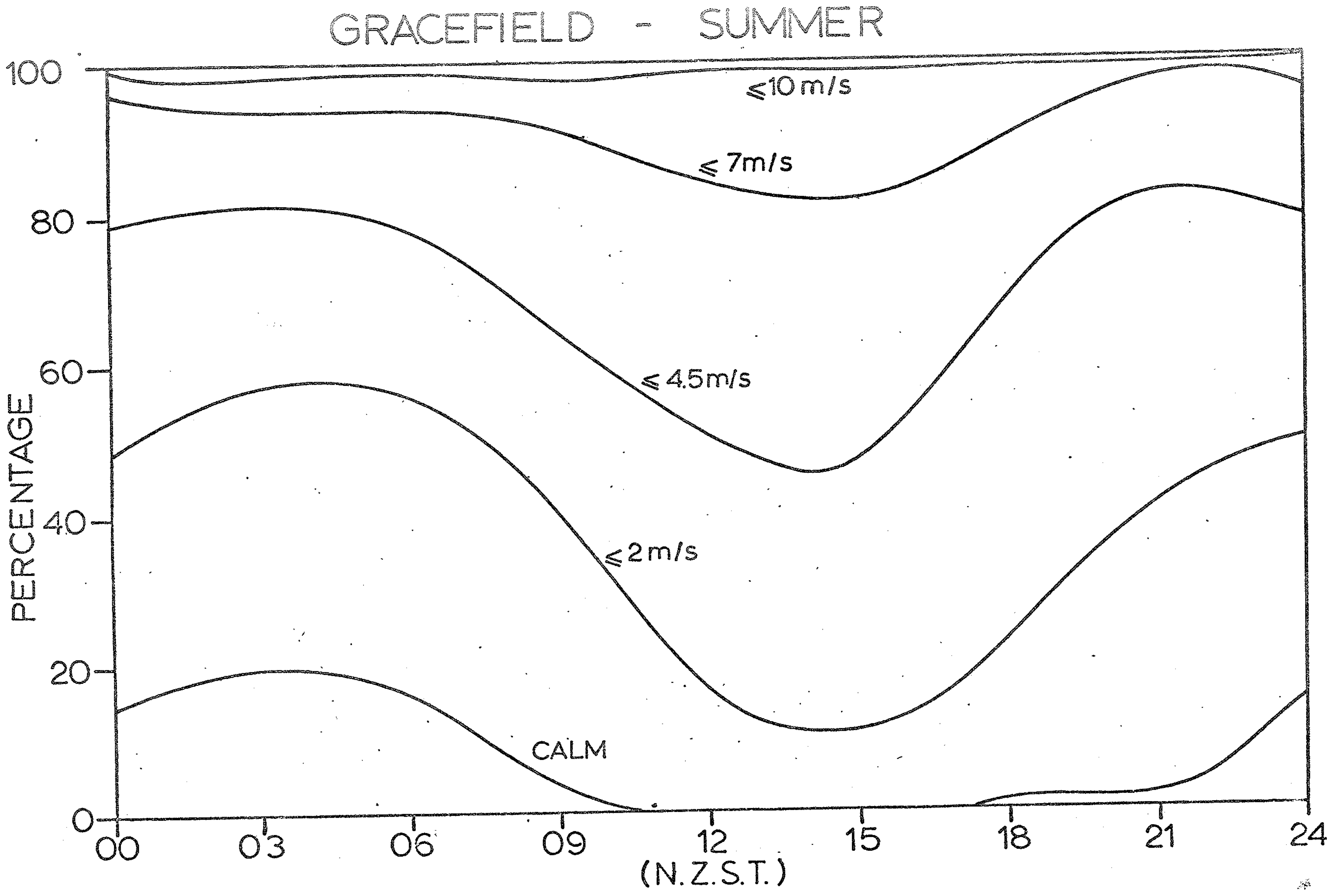

Fig. 3(b) Frequencies of winds less than values specified.

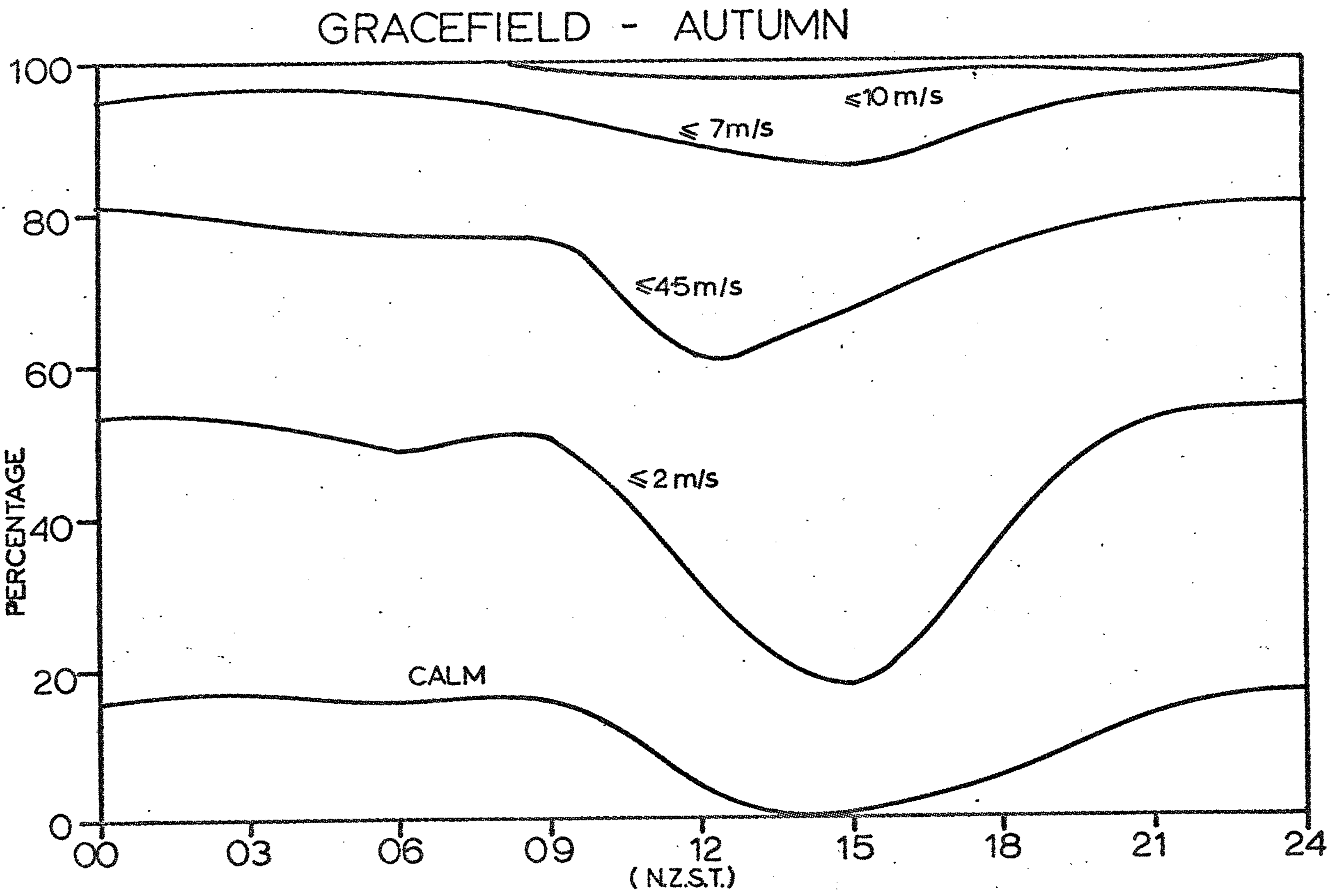

Fig. 3(c) Frequencies of winds less than values specified.

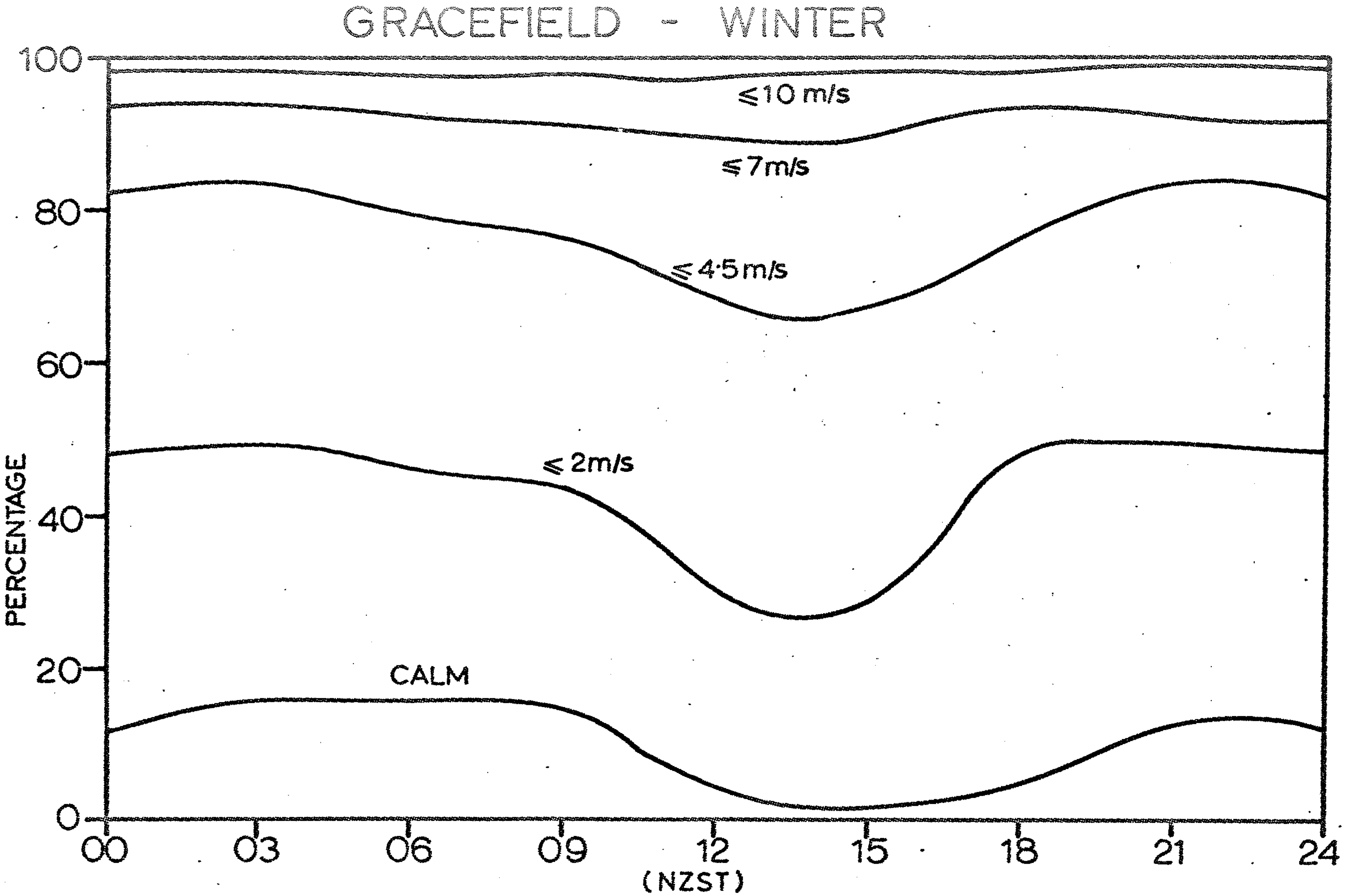

Fig. 3(d) Frequencies of winds less than values specified.

on these have already been described above. More recently a further series of flights has been made from Gracefield in connection with another study. Analysis of these is at present incomplete, but preliminary results suggest a similar behaviour to the Seaview series.

In the majority of cases, flights were made under fairly light wind conditions. For practical reasons, no flights were made during the night.

Figures 4a - d show the trajectories grouped according to the wind directions recorded by the Gracefield anemometer at time of flight. This classification is only indirectly related to the airflow aloft and some deviations in trajectories will be noted where balloons have risen through the surface layers into different airstreams.

(a) Gracefield wind northerly

The trajectories are spread about a fairly broad cone with main axis in the southerly direction. A closer inspection of the data show that flights in stable conditions tended west and in less stable conditions to the east of the average track. Flights 43 and 44 were made in the mid-afternoon and were carried up and over the eastern hills. A light northeasterly drift was present in the southeastern part of the Hutt Valley for flights 10 and 11, but there was a moderate southeasterly above 90 m altitude into which the balloons rose.

(b) Gracefield wind northeasterly

In this category the trajectories are mostly confined to a relatively well-defined track, somewhat west of south and parallelling the eastern side of Wellington Harbour. The two flights (17 and 18) which passed over Lowry Bay were made on a clear afternoon, with good dispersal conditions and a light northwesterly aloft which backed to southwest at higher levels. Flight 12 was made in the late afternoon, but with excellent visibility and obviously good dispersion conditions. There was a moderate easterly flow aloft, tending northeasterly at higher levels.

(c) Gracefield wind southerly

Only a limited number of flights were made in this category. In all cases the trajectories were confined to a narrow cone parallel to the general topography while the balloons remained below 2-300 m, but deviations

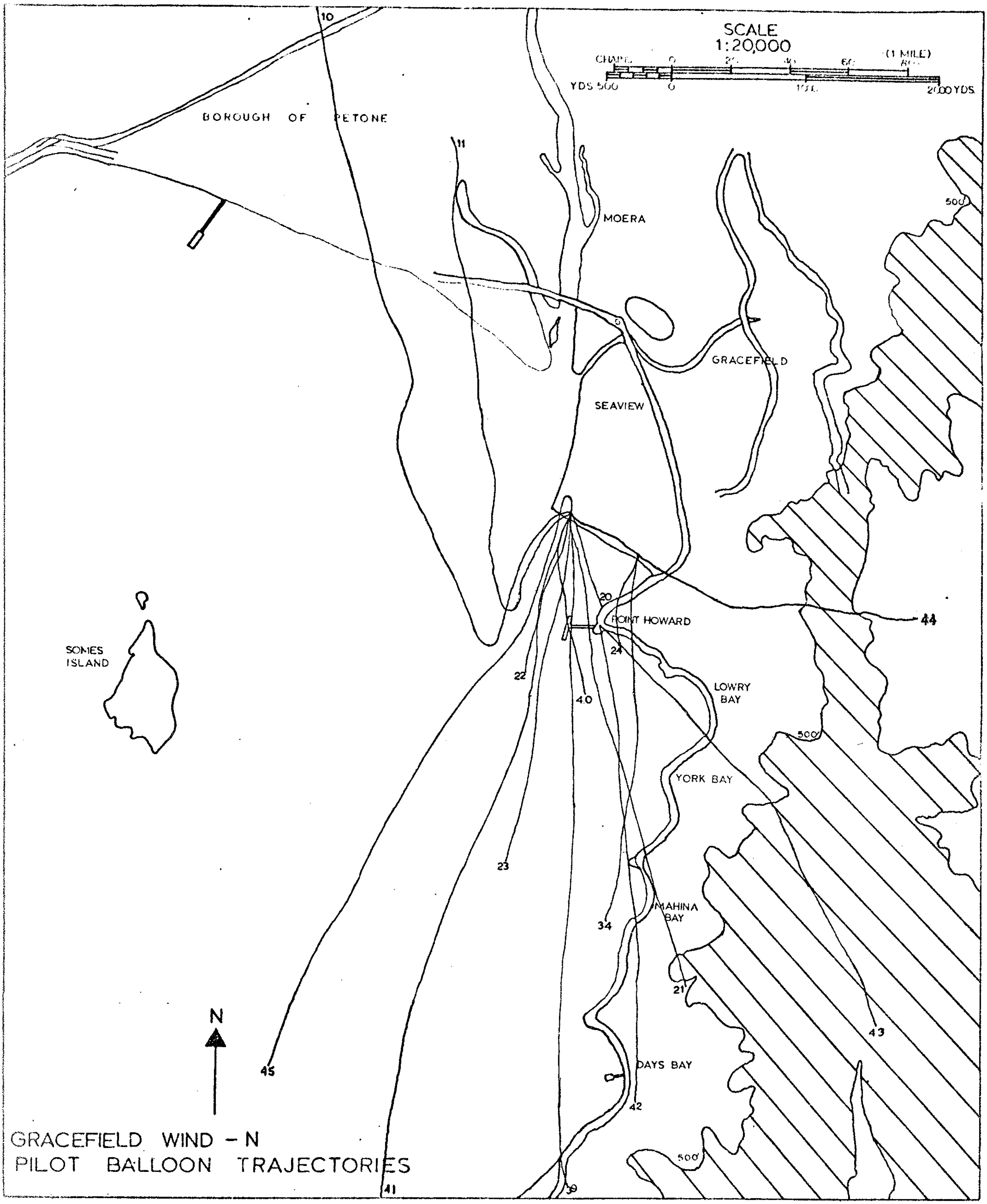

Fig. 4(a) Gracefield wind - N. Pilot balloon trajectories.

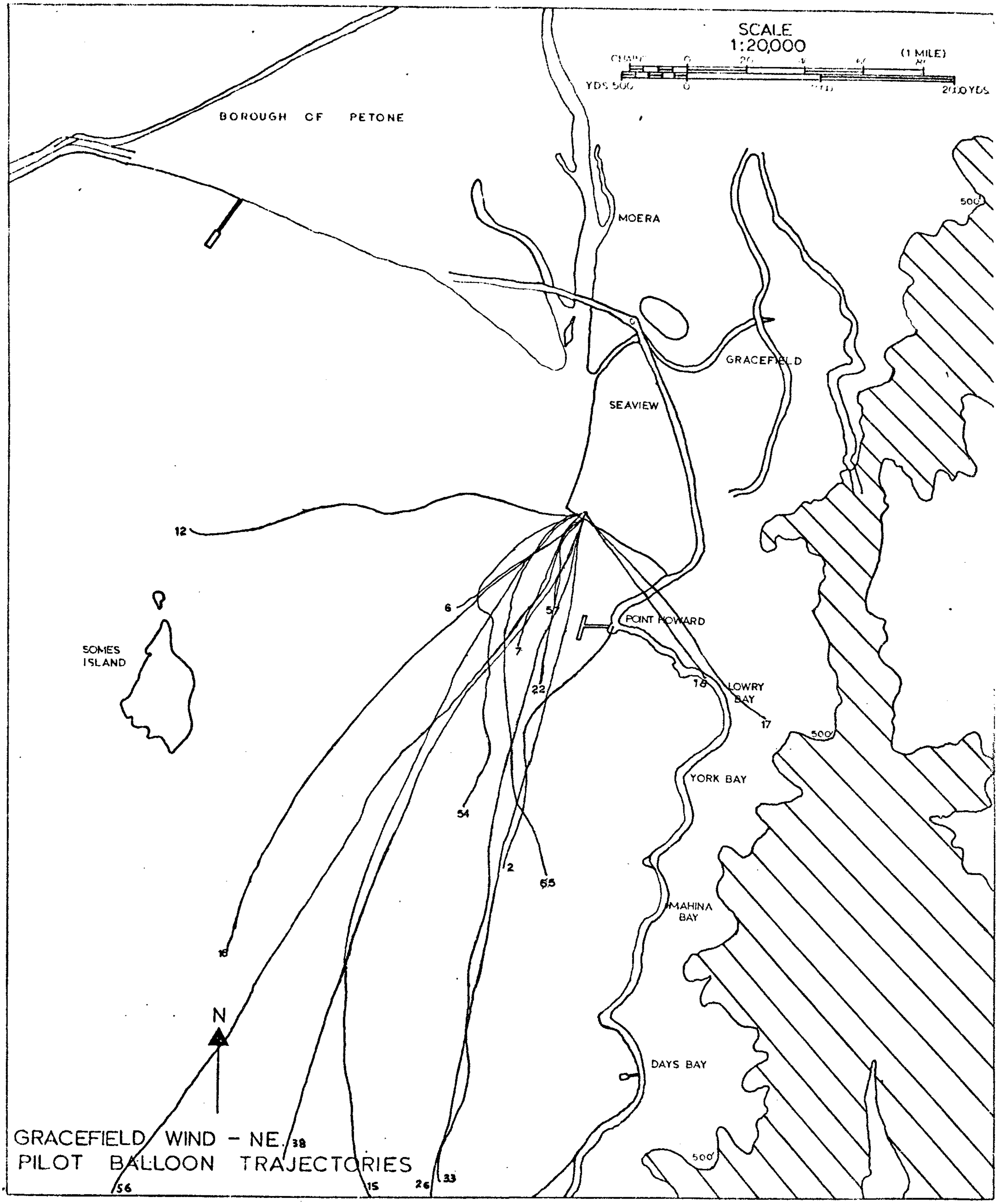

Fig. 4(b) Gracefield wind - NE. Pilot balloon trajectories.

occurred at higher levels. For flight 1 the rate of ascent was greater than desired and the balloon rose into a fresh southeasterly above about 250 m, and it reached over 800 m by the end of the flight. Flights 14 and 64 were made in unstable afternoon conditions, with variable winds. The two longer flights (31, 61) were made in moderate winds, with the balloons remaining below 200 m throughout. The constancy of direction is noteworthy.

(d) Gracefield wind southwesterly

A fairly large number of flights, distributed through the daylight hours, were made under this category which, as mentioned above, is often associated with sea-breeze effects. With only a few exceptions the flights were grouped relatively closely around a mean trajectory (allowing for the two different release points) which follows a northeasterly direction parallel to the general topography, and curving slightly towards the east. Flight 47 rose through an inversion layer at about 100 m into a northeasterly drift aloft. Flights 69, 70 and 74 were all released on the same afternoon. The light drift towards the east above about 150 m in all three flights did not seem to be related to any large-scale feature as the winds at higher altitudes were light and variable.

Summarizing the above results, one can say that balloons which remained fairly low (below say 250 m) tended to be channelled along fairly well-defined paths. In stable conditions these paths parallelled the general topography along the eastern side of the Hutt Valley and Wellington Harbour with only moderate deviations about the mean track. In less stable conditions, including those giving northerly winds at Gracefield as distinct from northeasterlies, there was more variability in the trajectories and a tendency for them to be more to the east of those in more stable conditions. On unstable afternoons balloons were sometimes carried eastward up and over the eastern hills. In those cases where the rate of ascent was larger, balloons were often carried into upper-level flows deviating radically from those in the surface layers.

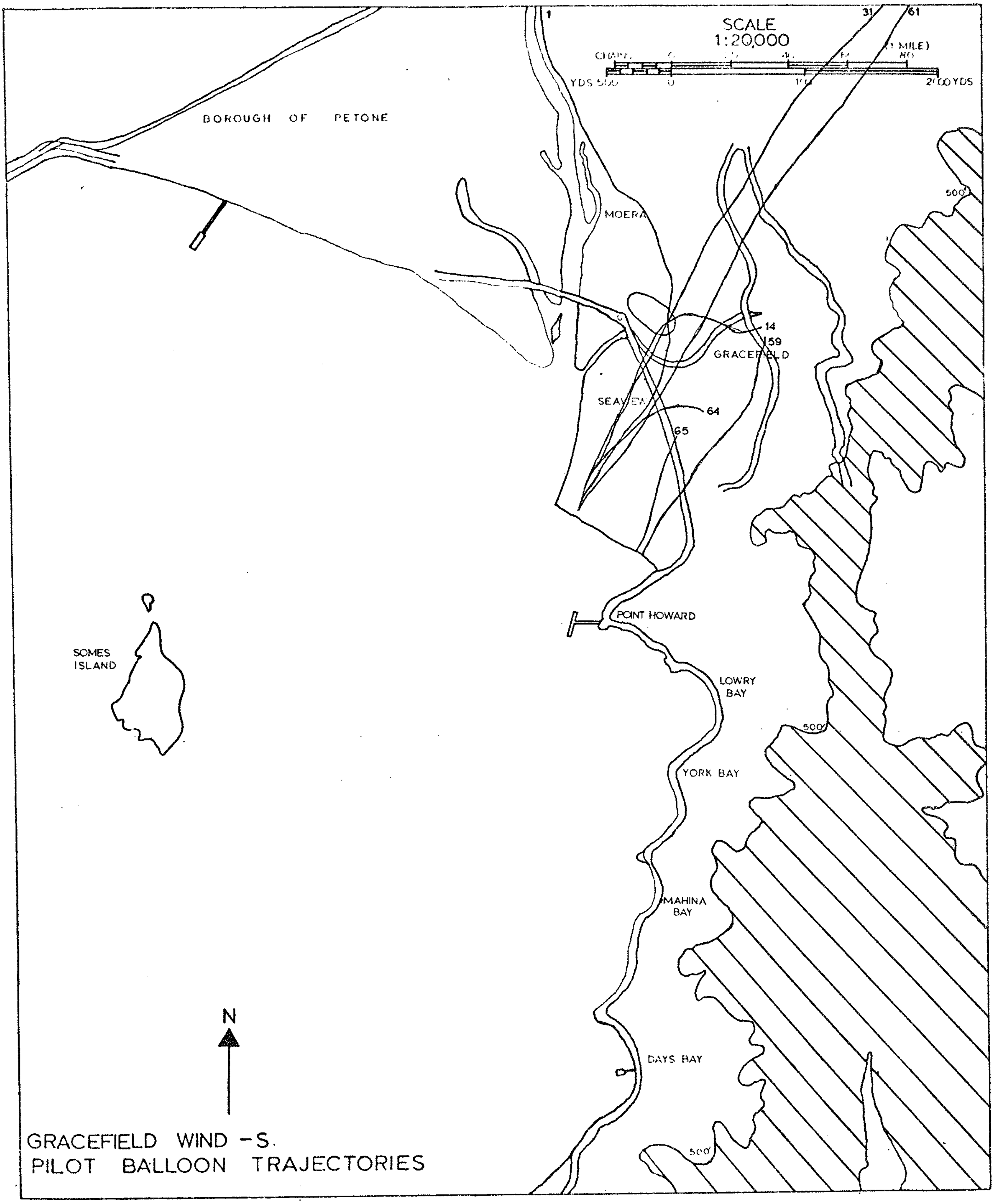

Fig. 4(c) Gracefield wind - S. Pilot balloon trajectories.

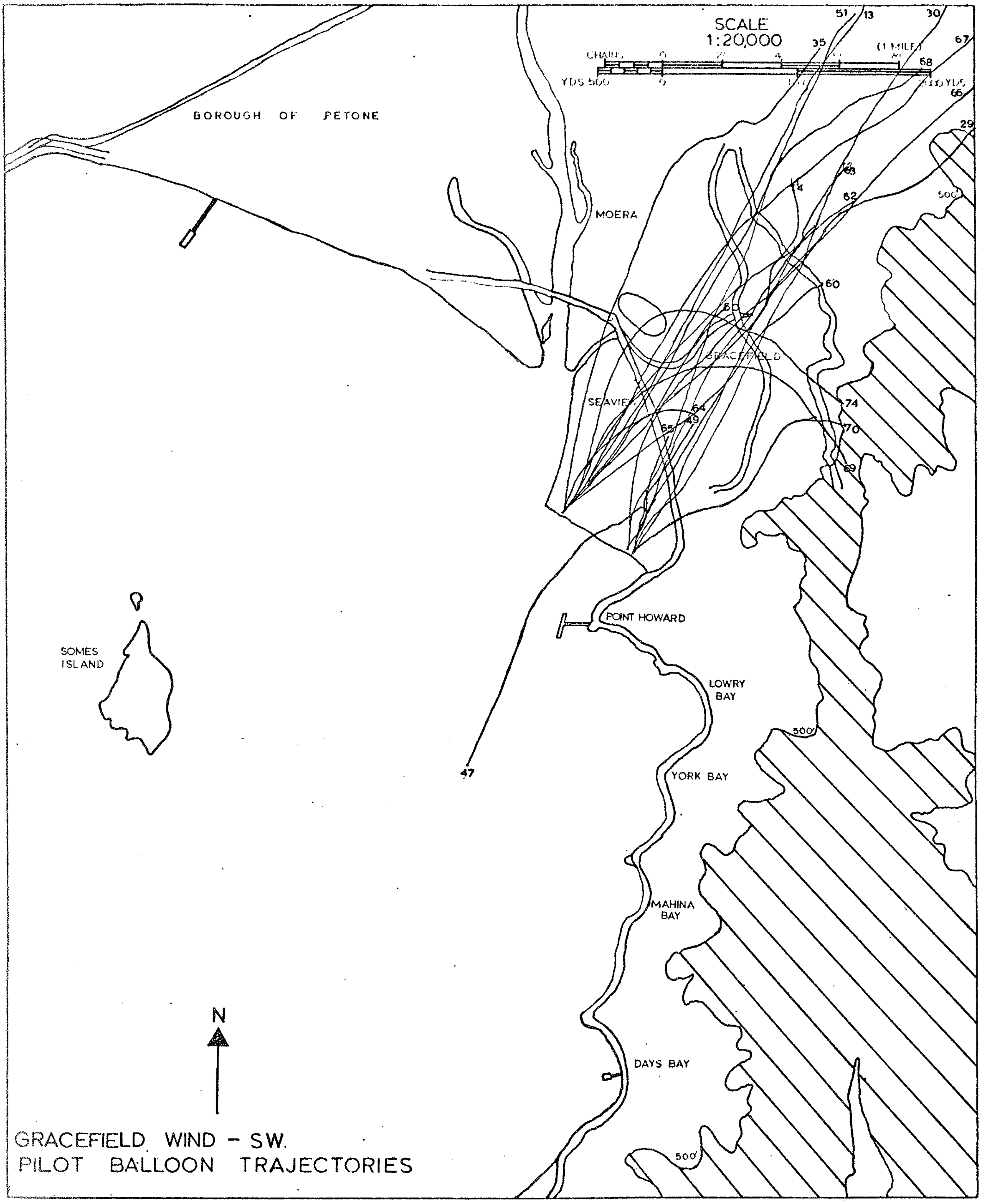

Fig. 4(d) Gracefield wind - SW. Pilot balloon trajectories.

Temperature Soundings

A limited amount of data have been obtained relating to the temperature stratification in the southeastern Hutt Valley. Aside of the tethered balloon soundings of Kidson, mentioned above, a programme of measurements has been in operation at Gracefield during the 1973 winter using a tethered "kytoon" to suspend temperature sensors at heights up to 200 m. Temperatures are recorded at 50 m height intervals plus a fifth point at 1 m above the ground. Temperatures can also be recorded while a single sensor is hauled up and down. Measurements have been confined to mornings with calm or very light winds, when temperature inversions might be expected.

A second and promising new source of data is the acoustic radar being developed at Gracefield as a joint Meteorological Service - D.S.I.R. project. With this equipment a vertically-directed pulse of sound is scattered back to the receiver by certain types of temperature discontinuities in the atmosphere. The latter include microturbulence produced at the boundaries of inversion layers under certain conditions.

Interim results of these two projects plus a discussion of a third source of information - the observation of smoke layers, will be discussed below.

(a) "Kytoon" soundings

Figures 5a - d show examples of the temperature soundings, plotted in the form of 15 minute mean temperature vs height. All soundings were made in near-calm, settled conditions and all show inversion layers in varying degrees. Because of the hills to the east of Gracefield the curves plotted for the earliest times in each case represent pre-sunrise conditions. The effect of solar heating in breaking up the inversion later in the morning is clearly seen.

Table 2 shows a preliminary analysis of the low-level inversion layers at 0800 N.Z.S.T. on 13 near-calm mornings. Where two layers were present, the temperature difference ΔT between the top of the inversion and the 1 m level is taken with respect to the higher layer. The right-hand column of the table gives the difference in potential temperature between the top of the inversion layer and the 1 m level, obtained by adjusting ΔT by h times the dry adiabatic lapse rate.

These results show that around 100 m is a common height for the top of the low-level inversion layer, although in well developed cases a height of 200 m or so may be expected. On some occasions inversion layers occur below 50 m, but these are usually accompanied by higher layers.

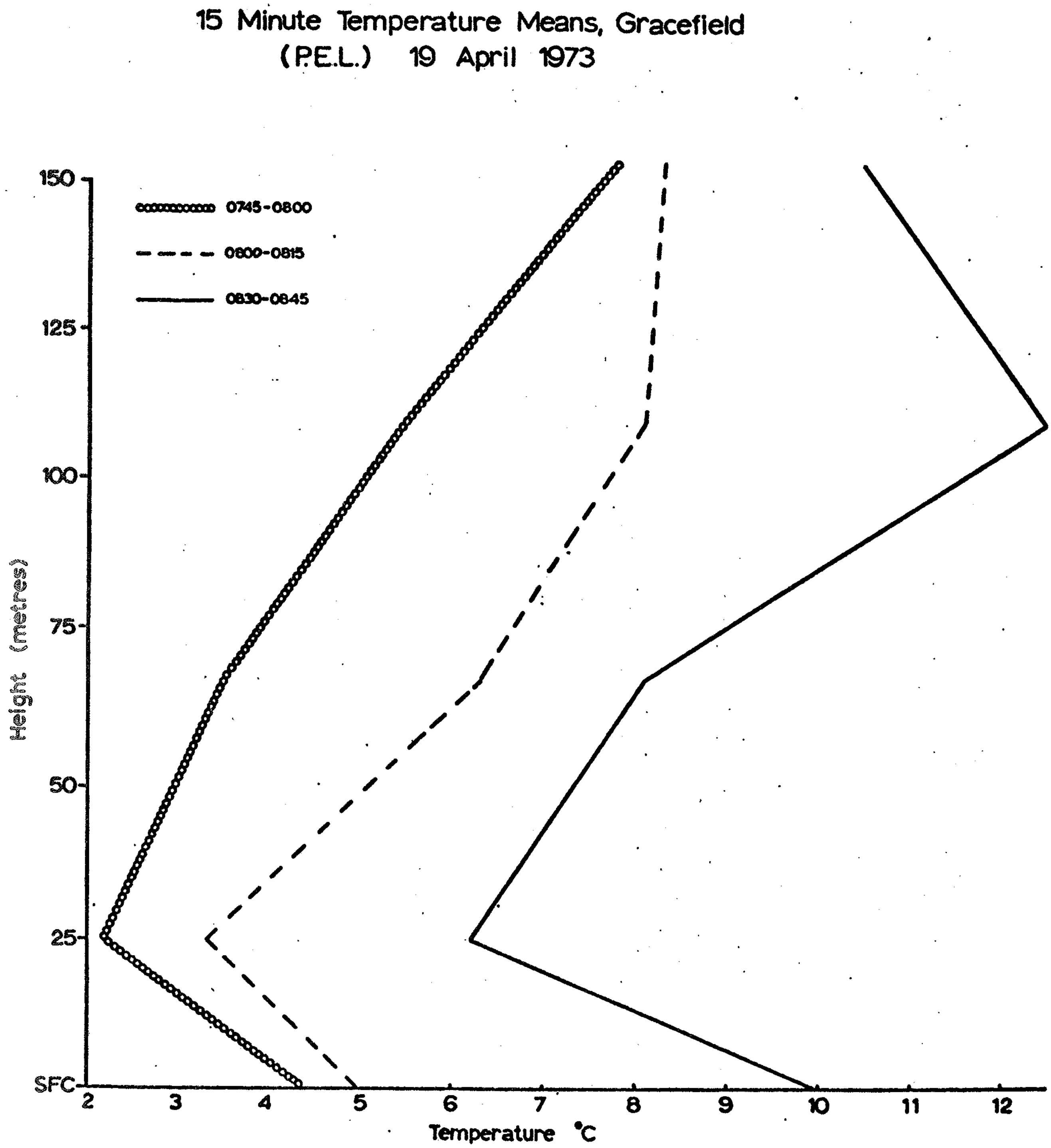

Fig. 5(a) 15 Minute temperature means, Gracefield (P.E.L.) 19 April 1973.

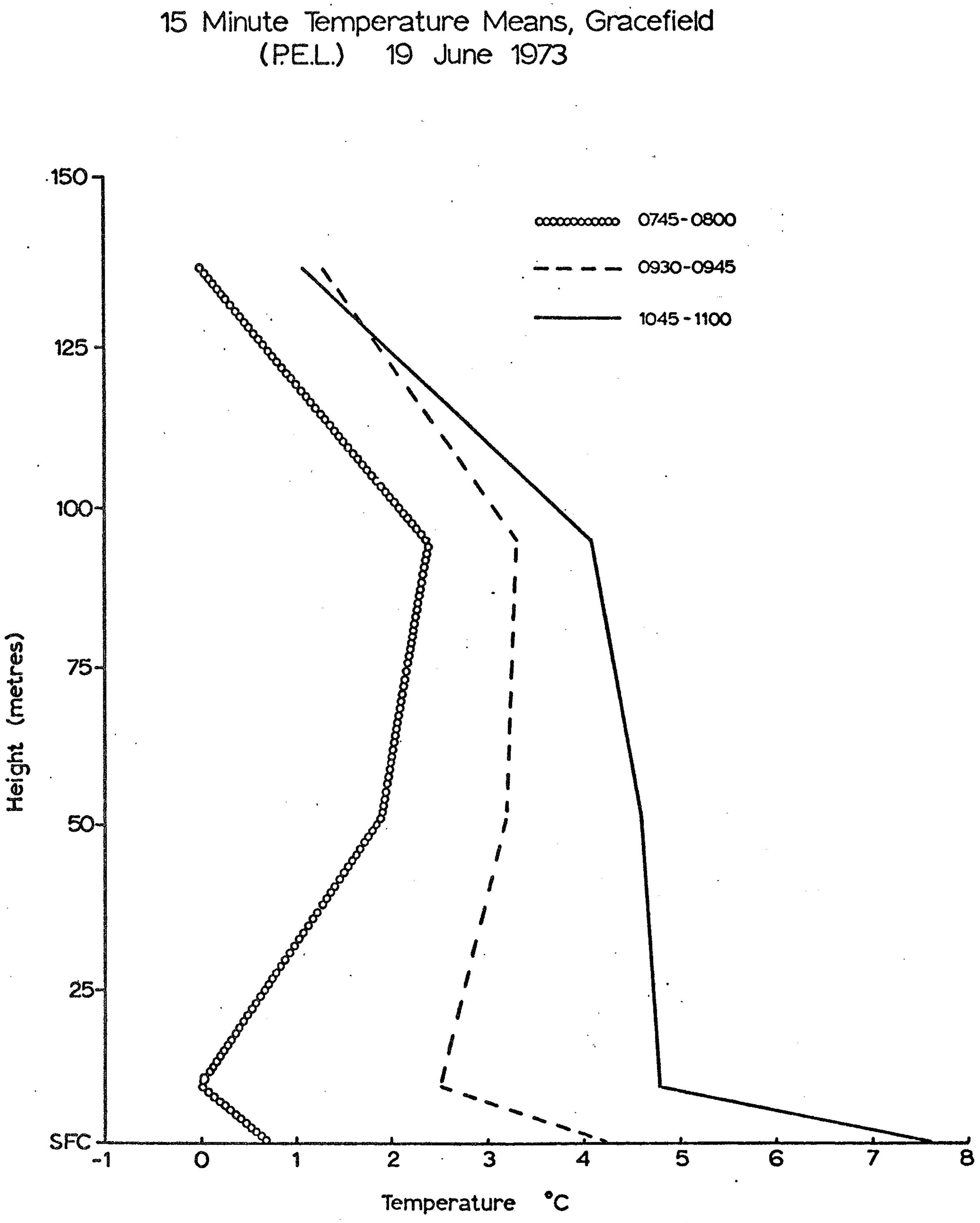

Fig. 5(b) 15 Minute temperature means, Gracefield (P.E.L.)
19 June 1973.

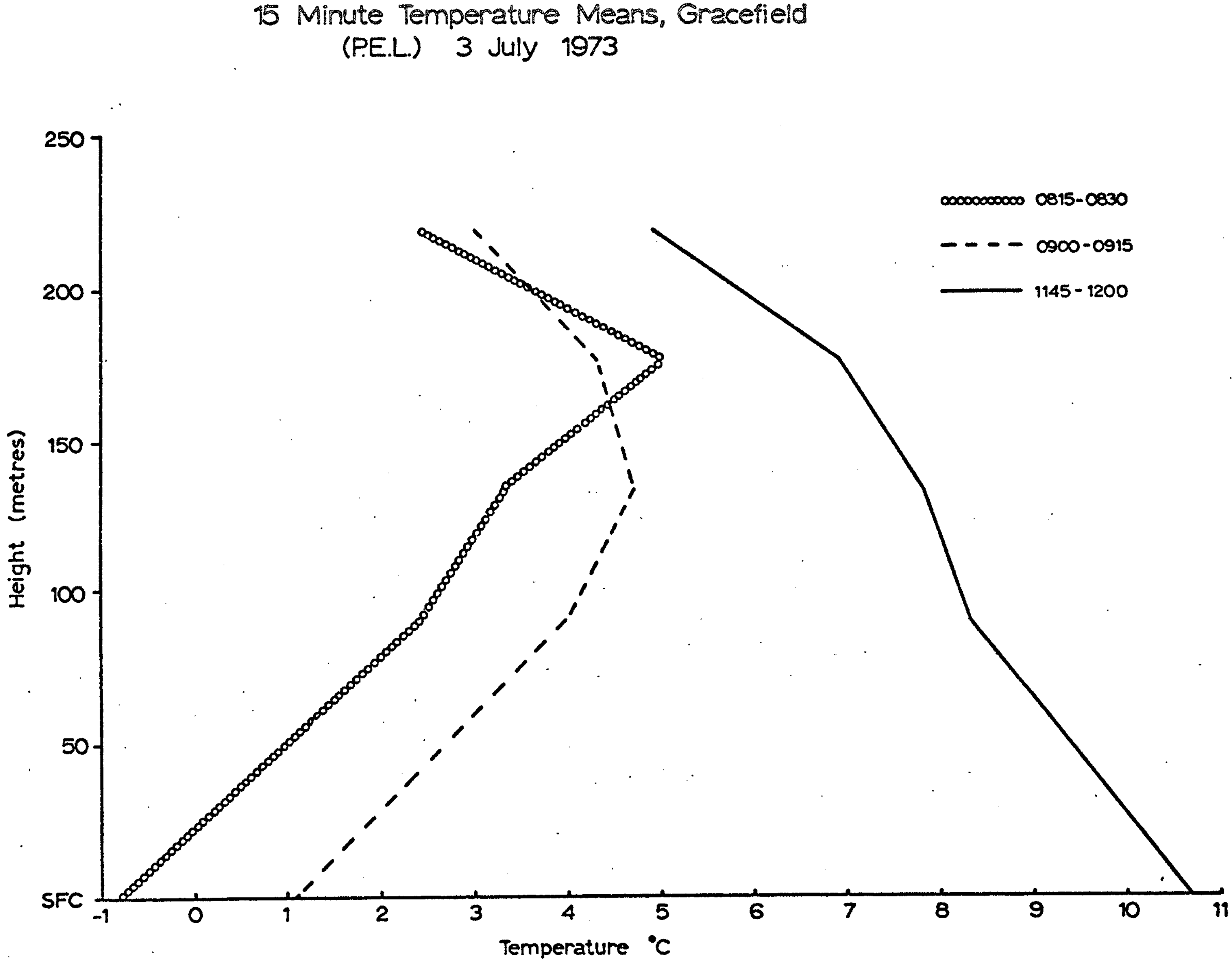

Fig. 5(c) 15 Minute temperature means, Gracefield (P.E.L.) 3 July 1973.

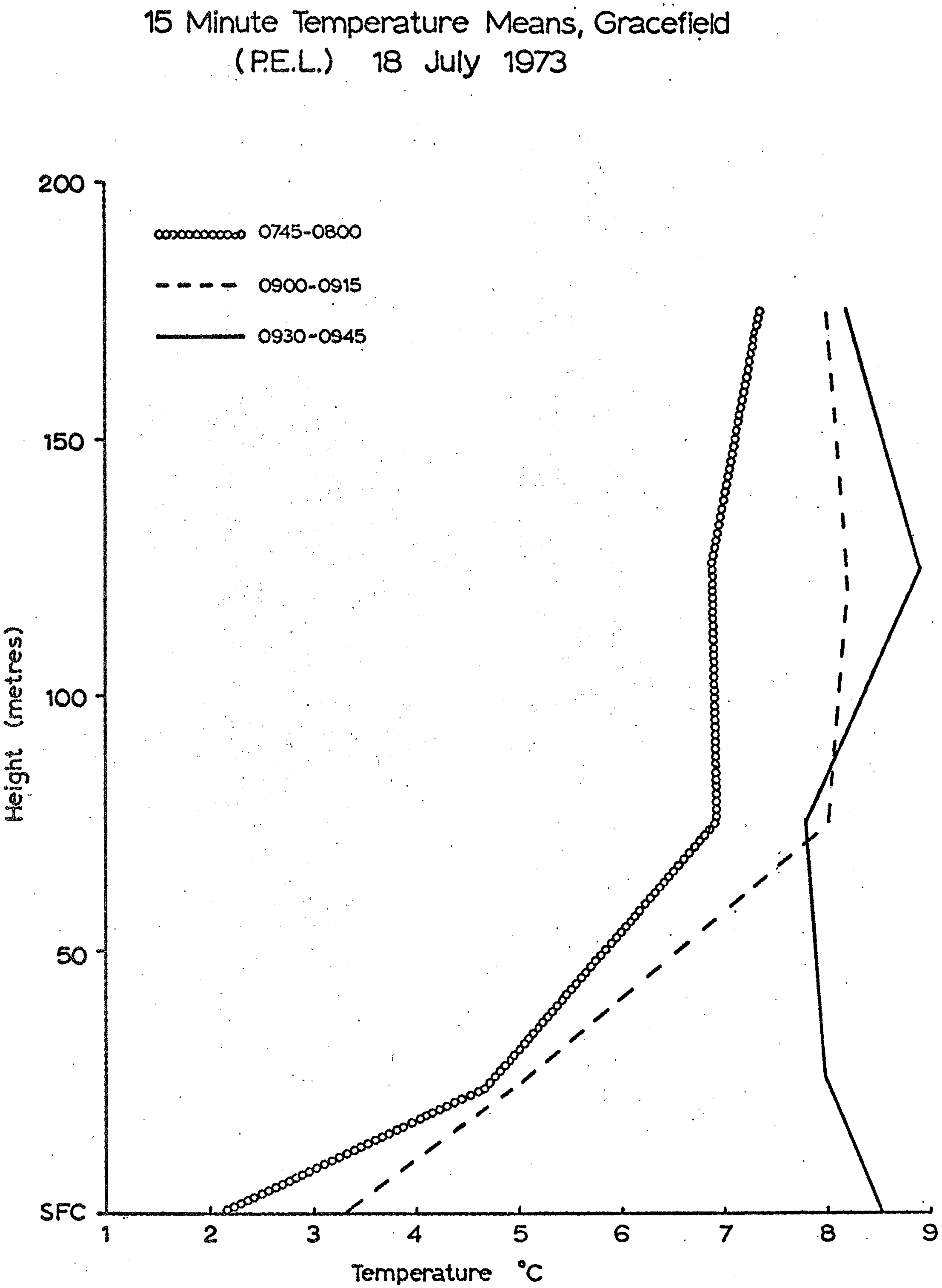

Fig. 5(d) 15 Minute temperature means, Gracefield (P.E.L.) 18 July 1973.

Table 2. Heights and strengths of low-level inversion layers observed at 0800 N.Z.S.T. in near-calm, settled conditions, at Gracefield.

Date	Height of Layer Top, h	$\Delta T = T_h - T_1$	$\Delta\sigma$
19. 5.73	160 m*	3.6°C	5.2°C
12. 6.73	30 m, 110 m	2.9°C	4.0°C
13. 6.73	16 m, 100 m	0.8°C	1.8°C
19. 6.73	100 m	1.7°C	2.7°C
20. 6.73	8 m, 95 m	0.7°C**	1.6°C
21. 6.73	100 m	2.6°C	3.6°C
3. 7.73	190 m	4.3°C	6.2°C
4. 7.73	110 m	3.9°C	5.0°C
9. 7.73	170 m	4.5°C	6.2°C
10. 7.73	170 m	3.0°C	4.7°C
13. 7.73	50 m	0.6°C	1.1°C
18. 7.73	170 m	5.5°C	7.3°C
19. 7.73	200 m***	6.0°C	8.0°C

* Base of inversion layer at 25 m

** Increased to 1.7°C at 0930 N.Z.S.T.

*** Between 0815 and 0915 N.Z.S.T. the top of the inversion lowered to 150 m.

(b) Acoustic Sounder

As this equipment is strictly in the development stage and the echoes observed with it require considerable interpretation it is not yet possible to draw more than very tentative conclusions. Due to present instrumental limitations it is also not possible to be definite about echoes from below about 60 m.

Echoes observed at Gracefield in May and June 1973 appear to be sometimes from columns of microturbulence (possibly extending down to ground level) and sometimes from layers of microturbulence. When the columns extend well into daylight hours they are thought to mark the passage of columns of rising warm air (thermals) drifting through the radar beam. Such columns typically occur in settled conditions between 11 a.m. and 4 p.m. and have tops in the altitude range from below 60 m up to 200 m.

Layers of microturbulence lie mostly in the range from below 60 m up to 140 m, with primary preference for about 60 m and a secondary preference for 120 m. Occasionally layers are seen above 140 m and up to 190 m. The layers usually wave up and down and sometimes exhibit a herringbone pattern characteristic of breaking waves. Steady or only gently waving layers of microturbulence may occur from about 1800 N.Z.S.T. through to noon in near-calm, settled conditions. Between 1900 and 0700 N.Z.S.T. the layers may become choppy or break, and from about 0300 may develop into columns of echoes resembling the daytime thermals but extending to rather smaller altitude.

It is thought that the layer echoes above 100 m are from the tops of inversion layers and that the intensity of echoes and the tendency towards breaking are related to the size of the discontinuity in temperature gradient and the vertical wind shear across this region. The origin of the lower-level layer echoes is not certain. In some cases, but not always, the kytoon soundings show a lower-level inversion at the same time. Probably the layers are related to wind shear or mechanically-induced turbulence in conjunction with a strong vertical temperature gradient, but direct correlation with the latter is not obvious in the results so far obtained.

(c) Smoke Layers

When an inversion layer develops, smoke from domestic and industrial sources in the Hutt Valley is trapped within it. Such layers of smoke are frequently clearly visible, especially from high ground surrounding Wellington Harbour from which one looks obliquely through them. Many photographs and some written descriptions of these layers have been made but unfortunately no systematic studies of their frequency or relation to broader scale meteorological features.

The smoke layers are likely to be visible almost any early morning on which stable anticyclonic conditions prevail and winds are less than 2-3 m/s. Their development appears to be favoured by clear-sky conditions but they do occur with cloudy skies. Dissipation of the layers varies from an hour or so after sunrise in summer to late morning or even midday in winter. In the latter season they often re-form in the late afternoon.

Recorded estimates of the heights of the tops of these smoke layers have mostly been around 100 m, though occasionally as low as 50 m and as high as 180 m. While these heights are consistent with directly-measured heights of inversion layers it has to be admitted that horizontal variations in the smoke plumes can introduce misleading perspectives which can seriously affect estimated heights in individual cases.

It is hoped that when interpretation and some instrumental problems are resolved the acoustic radar will provide considerable information in the frequency of occurrence and nature of inversion layers. In addition, it may give useful information on dispersion in non-inversion conditions. It is intended that the programme of direct soundings in selected conditions will be continued. This latter programme will be supplemented by special radiosonde flights which will give information on conditions above the level attainable with the kytoon. This will assist when the low-level inversion extends above this level and will also allow observations of higher-level inversion layers. Such layers, due to larger-scale dynamic effects, are expected in anticyclonic conditions, probably around 600-1000 m.

The Valley Circulation and the Dispersion of Pollution under Stable Conditions

As mentioned above it is necessary to consider in some detail the behaviour of pollution in conditions when dispersion is likely to be poor. This section deals with those situations where the pressure gradients are weak, such as when an anticyclone coversthe area, and the winds are light and determined by local temperature contrasts rather than the larger scale circulations. The frequency of occurrence of such conditions in the Wellington-Hutt Valley area has not been determined over a long period of years but during the past (1973) winter they occurred in a fairly well-developed form on between 10 and 15% of days. The effects to be described are also often present to some degree when pressure gradients are greater.

When pressure gradients are very light the surface wind in the lower Hutt Valley and in the northern part of Wellington Harbour behaves similarly to the idealized valley circulation as described by Defant (1951). At night and in the early morning there is a drainage of cold air from the north, out of the valley. Later in the morning and during the day, under the influence of solar warming, the wind changes to a light southerly which is reinforced by a "sea-breeze" effect due to the land-sea temperature difference. Observations of smoke drift suggest that these northerly and southerly drifts are more developed on the eastern side than the western side, probably because the harbour is open to the south on the former side. These effects are evident in the Gracefield wind analysis. The valley circulation also involves a cold drainage flow down the flanking slopes at night, which is consistent with the tendency for the night-time drift at Gracefield to be northeasterly rather than more northerly.

The net effect of the valley circulation is the accumulation of a pool of comparatively cold air in the lower Hutt Valley and in Wellington Harbour overnight. To a substantial extent this cold air is trapped by the surrounding hills, although some escapes out through the harbour entrance.

An inversion layer usually forms in the cold air. This inversion usually but by no means always extends through the depth of the cold air. Occasionally there is mixing within the lower part of the cold air. This mixing was evident in some of the kytoon soundings, and is probably the explanation of why smoke is often fairly evenly distributed up to the top of the cold layer rather than remaining near the height of release. The mixing may be associated with the early-morning "breaking" of gravity waves in the inversion layers as recorded by the acoustic radar.

By mid or late morning, depending on the season, the surface layers become sufficiently heated to destroy the inversion at all levels.

It can be seen that pollution released through the night from the southeastern Hutt Valley into this pool of cold air will be trapped below the inversion layer and tend to accumulate overnight, reaching a maximum in the earlier part of the morning. For a source near the Hutt River mouth lateral dispersion in the northeasterly drift would be limited, with the axis of maximum concentration parallelling the eastern side of the harbour. Mixing within the inversion, due to breaking waves on the layer or, later in the morning, to solar heating, will result in increased ground-level concentrations under the plume.

After the destruction of the inversion in mid or late morning, pollution trapped under it can be expected to disperse rapidly and, apart from the "channelling" effect of the topography the situation will revert to the normal behaviour of a pollution plume appropriate to the prevailing wind and stability conditions.

If there is sufficient solar heating a southwesterly sea breeze often develops from late morning and lasts until late afternoon. There is a possibility that some pollution which had accumulated overnight in Wellington Harbour may be carried northwards over populated areas of the Hutt Valley by this breeze but such an effect should be offset substantially by the increased turbulent mixing by the time this happens. However it must be admitted that little is known of the details of the interaction between the valley circulation and the sea breeze.

If the sea breeze does not eventuate, the surface wind will depend on the synoptic situation. Pollution will still tend to be carried along fairly well-defined channels depending on the surface wind, as discussed in an earlier section and as implied in Kidson's computations. It should be recalled, however that there is a tendency for the flow to be more towards the east in less stable conditions and in some unstable afternoon conditions pollution may be carried eastwards across the eastern hills.

In the late afternoon and evening, conditions will become stable again as the ground cools by radiation and there will again be a tendency for pollution released at low altitude to build up. Some may be carried up the eastern side of the valley, especially if the southwesterly wind persists longer than usual as might happen if there was a southerly gradient wind. However in most cases the wind becomes calm as the temperature falls, and the down-valley drainage of cold air will re-commence later in the evening.

If pollution is released above, rather than below, the inversion layer at the top of the cold air, the dispersion under stable conditions will be rather different during the night and early morning from that described above. The inversion layer will isolate the pollution from the ground (with the exception, of course, of the ground to the east), and there will not be the same tendency for pollution to build up overnight, since dispersion conditions can be expected to be better than in the cold air. The drifting balloon results suggest that up to about 300 m altitude the pollution will be channelled parallel to the topography in the same way as at lower levels, although the drift may at times be in the opposite direction above the inversion to that below.

A possibility that has not been fully investigated is that pollution emitted above the low-level inversion may be drawn down into the valley in the cold air draining down the sides of the valley at night. It is unlikely, however, that this would be significant as the polluted air could only enter the downslope flow over a limited region near ridge level.

In anticyclonic conditions a subsidence inversion may be present around 600–1000 m and pollution may be trapped below this even if it is emitted above the lower level inversion. Because of the greatly increased depth available for mixing it is not thought that the resulting build-up of pollution would be serious unless the source were of exceptionally high strength.

Conclusions

Meteorological factors are not ideal for the dispersion of atmospheric pollution from a site near the mouth of the Hutt River. This is because of the perhaps unexpectedly high frequency of light winds in the southeastern Hutt Valley, and the tendency for pollution to be concentrated along a narrow channel parallel to the eastern hills.

The formation of a low-level temperature inversion in the southeastern Hutt Valley and Wellington Harbour may be expected on a significant number of occasions, especially in winter. Pollution emitted at an effective height below the top of this inversion would tend to build up overnight, with consequent increases in ground-level concentrations because of "fumigation". For the most part such increases would occur over the eastern part of Wellington Harbour rather than over built-up areas, although some build-up may occur in the eastern Hutt Valley in the evening before the drainage flow is well-established. Pollution emitted above the low-level inversion level would not accumulate in this manner, but to achieve this on most occasions would require an effective stack height exceeding 150 m and preferably exceeding 200 m under the inversion conditions. This height should be easily obtained with a large installation such as a power station, with relatively high exit temperatures, but the requirement may present difficulties with other types of plant.

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