1981

WESC(81)GT 139

UK WAVE POWER PROGRAM

WAVE ENERGY STEERING COMMITTEE

The Availability Model

Consultant's Working Paper Number 32

JANUARY, 1981

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CONTENTS

SUMMARY

This note describes some results obtained from the Consultant's Availability Model. They are based on preliminary data provided by Y-ard on the reliability of devices, and by Kennedy & Donkin on the transmission scheme.

It is estimated that about 20% of the total energy output of a system might be lost due to repairs of its component. (This does not include lossed due to routine maintenance activities). Assuming a value of 5p/kwh, this is equivalent to a cost of about £40m per annum for a 2gw station. station.

There are several possible ways of reducing such losses, however, the most important being:

- The reduction of failure rates by improvements in design, added redundancy in critical areas, or additional preventive maintenance.
- The use of larger numbers of repair crews, boats, etc..
- The reduction of live repair times in order to take advantage of the short weather windows which occur during the winter months, and/or the improvement of access to devices so that repair work can be carried out in more severe sea conditions.

The trade-offs which exist between investing money in these areas and the resultant savings in energy losses are discussed, with the conclusion that the optimal solution for any scheme is likely to be one that reduces such losses to a minimum, by capital investment or high O+M expenditure.

The appendices give an outline of the Availability Model and a revision of the sea-state information given in Working Paper 24, based on a more extensive analysis of the data.

1 INTRODUCTION

Work on the improvement and use of the Availability Model has been proceeding over the last few months in close liaison with the Maintenance Group. This note sets out preliminary results and conclusions presented to the Group at their November meeting. The appendices contain a description of the model as it now stands and also an extended analysis of the sea-state data. Working Paper 24 is superseded by this note.

The note makes reference to three other reports:

- Progress Report. Development of Strategies for the French Flexible Bag and NEL Oscillating Water Column Devices. Y-ARD Ltd. October 1980.

- A Study of the Operation and Maintenance Costs of a UK Wave Energy System. Easams Ltd. February 1980.

- Reliability Study of Typical Electrical Power Collection and Transmission Scheme. RPT/K&D. (Working Paper 22) November 1980.

The term 'System Availability' is used in several places. It is described fully in Appendix A, but a brief definition is 'The ratio of the energy produced by a wave energy system to that which would be produced if all its components always functioned'.

2 AN ESTIMATE OF SYSTEM AVAILABILITY (S.A.)

Figure 2.1 shows the percentage of total energy lost from a scheme throughout the year. The losses are solely due to failures in component parts of the scheme. The assumptions on which the calculation is based, are as follows:

2.1 Devices

- Y-ard failure rates for a particular device. (14 failures per year per device causing complete shutdown of the device, plus a similar number causing small degradations in performance. The former occur in the hydraulic control and cooling systems, the latter in such items as louvre valves, etc..)

- Y-ard Repair Strategy 4. (Failures which result in complete loss of output are repaired as soon as possible, others are attended to as and when the opportunity arises.)

- Failures of moorings are ignored. (These may have high costs for maintenance and repair, but because of their infrequency they may not significantly affect power production.)

- Sufficient repair crews to avoid all queueing, thus the delays in the repair operation are caused only by adverse sea conditions.

- 24h 'good weather' period required for repair. (Taken to signify $Hs \leq 3m$.)

2.2 The transmission scheme

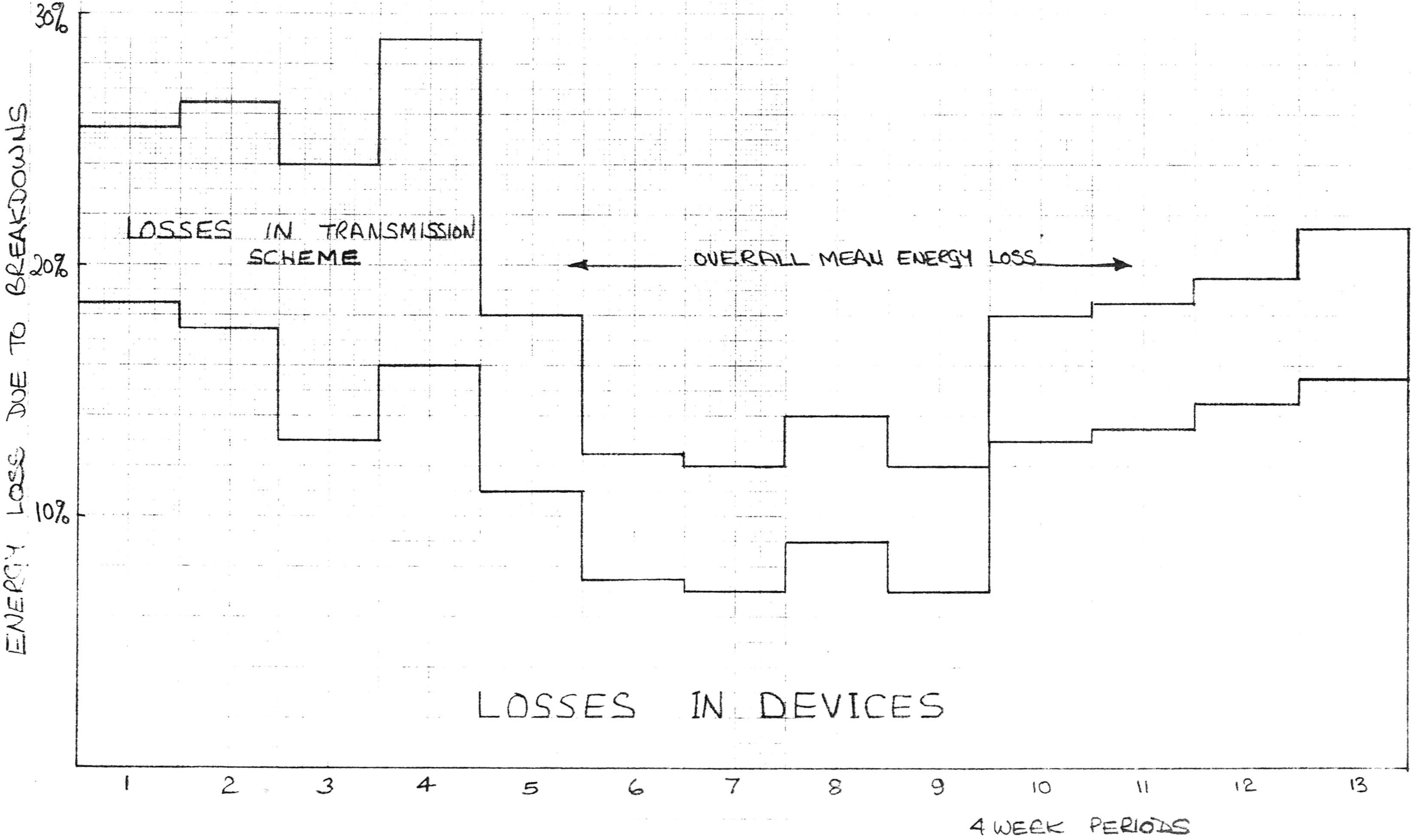
The next stage of the availability work is to incorporate data on the transmission scheme into the model. For the purposes of this note the Kennedy & Donkin figures are taken from Working Paper 22.

2.3 The Results

The proportion of energy lost throughout the year is approximately 20%. This is made up of 13% at the devices and 7% in the transmission system. The figures do not include losses due to routine maintenance tasks.

The remaining sections look at ways of reducing this figure as it relates to devices, and the cost trade-offs involved. Thus the above assumptions are taken as the base case and individual parameters varied, to assess the effects of such changes.

FIG 2.1 ENERGY LOSSES THROUGHOUT THE YEAR.



3 THE TRADE-OFF BETWEEN SYSTEM AVAILABILITY AND INCREASED RELIABILITY

The Y-ard figures for failure rates may come down, with suggestions for improved design in the critical areas (e.g. the control system). Such changes will affect the capital cost account if either 'better equipment' or redundancy are recommended. How much is it worth paying to increase S.A.?

- If we assume 5p/kwh, annual output of a scheme is worth about £220m pa.
- i.e. £2.2m per year is lost with each 1% unavailability.
- With a discount rate of 5% and a 25 year life, this is equivalent to a capital cost of between £30000 and £60000 per device, depending upon the number of them that make up the 2gw scheme.

Hence, if by spending up to this amount on a device, its S.A. is increased by 1%, the investment is worthwhile.

(For the whole transmission system the equivilent figure is about £30m.)

Table 3.1 shows how system availability is affected by changes in the number of failures causing loss of power. As these reduce, less visits are made to the device each year (under Repair Strategy 4) and the 'degradation' failures assume greater importance. While other strategies have not been studied at this stage, it is obvious that better results could be obtained if such repairs were attended to at more frequent intervals

Table 3.1 Energy Losses as a function of failure rates for those failures causing complete loss of output

FAILURE RATE	ENERGY LOSS DUE TO THESE FAILURES	ENERGY LOSS DUE TO DEGRADATION FAILURES	TOTAL ENERGY LOSS
14	9%	4%	13%
11	7%	5%	12%
8	5%	6%	11%
5	3%	10%	13%

4 THE TRADE-OFF BETWEEN SYSTEM AVAILABILITY AND NUMBERS OF REPAIR TEAMS

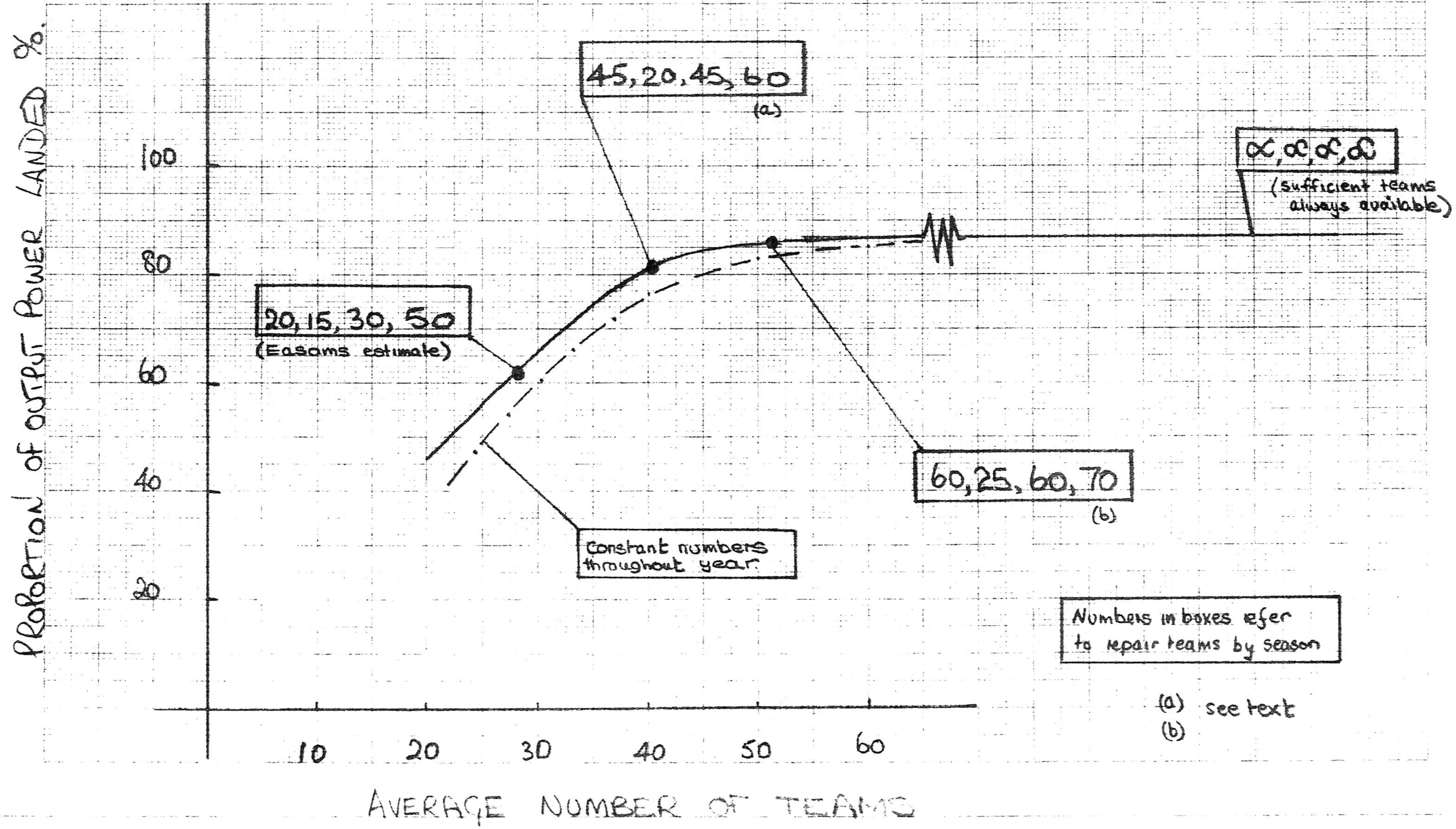
Figure 4.1 shows the S.A. of devices for different numbers of repair teams, that is the queueing for repair resources is now being introduced to the calculations. Using the Easams number of teams leads to about 35% of the output being lost (i.e. S.A. is 65%). At the other end of the scale the least that can be lost is 13% (S.A. is 87%).

To get some idea of where the optimum levels might be, consider the two intermediate results (points marked (a) and (b)). For an additional 10 teams S.A. increases by 3%, which in cost terms is £6.6m. These additional teams and their associated back-up requirements will cost considerably less than this figure.

Adding a further ten teams gives much less benefit - say 0.5% or £1.1m.

FIG 4.1 SYSTEM AVAILABILITY AS A FUNCTION OF REPAIR RESOURCES

(devices only)



5 CONVERTING TEAMS TO MANPOWER

Y-ard assume that two 12h shifts will be necessary for each repair, Easams assumed one. In addition the Y-ard teams (under strategy 4) will be working on more than one problem at a time. This implies larger teams in each shift.

The Easams multiplier was:

3(Men/Team) X 2(Off-Rota Crews) X 1.1(Sickness, etc.) = 6.6

The Y-ard multiplier seems to be:

4(Men/Team) X 2(Twelve hour shifts) X 2(Off-Rota Crews) X 1.1(Sickness, etc.) = 17.6

(N.B. This is purely our interpretation of preliminary information given in the Y-ard report).

Using the above multipliers the number of men required is as follows:

	EASAMS	'Y-ARD'
SPRING	123	1056
SUMMER	85	440
AUTUMN	189	1056
WINTER	302	1232

6 THE USE OF LABOUR ON A SEASONAL BASIS

There is some debate as to whether the 'hire and fire' policy implicit in the above figures will be possible as a high level of skills will be needed. If the labour force for repair was kept constant throughout the year, a total of about 60 teams would probably be required. Using the 'Y-ard' multiplier, this implies a constant labour force of 1056.

The situation in fact is rather better than this as what Easams termed service and overhaul work, is considered a summer activity. The offshore parts of this work could be carried out by the labour force given above, with little effect on availability.

7 TRADE-OFFS INVOLVING IMPROVEMENT OF ACCESS AND SHORTER LIVE REPAIR TIMES

The two most sensitive variables in all the above calculations are:

- Duration of the weather windows required.
- Definition of 'good weather'.

To show how important they are, the table below shows how the amount of lost power varies with changes in these variables.

Duration req'd limiting Hs	12h	24h	36h
2m	15%	24%	30%
3m	8%	13%	16%
4m	7%	10%	13%

NOTES

1. Assuming ample resources - i.e. delays are only to do with weather.
2. Refers to devices only.

8 CONCLUSION

The figures quoted in this note are very tentative. They may even be artificially pessimistic as a majority of the device failures occur in two areas, the control and cooling water systems. While both are required in any type of device, some development teams have already switched from hydraulic to electric control systems, with the knowledge that the former are very unreliable. In addition, simple air cooling is thought to be possible in many cases.

There is, however, an important conclusion to be drawn from the work, even with its present reservations. This is that energy losses due to breakdowns are both expensive and alterable. The cost penalties associated with periods of unavailability are large enough to warrant considerable extra investment either in O+M or capital equipment. The optimum solution for any scheme is likely to be one that goes a long way towards minimising losses.

APPENDIX A THE AVAILABILITY MODEL

1 INTRODUCTION

This appendix describes the RPT Availability Model, a computer program which has been developed as one of a number of tools for assessing the performance of different configurations and types of wave energy scheme. The model is intended to explore the relationship between, on the one hand, the system configuration and the repair philosophy used to maintain it, and on the other, the amount of energy lost due to breakdowns. It will provide answers to the following types of question:

- How much of the potential wave-power produced by a particular scheme will be lost due to breakdowns of its component parts?

- How can this loss be reduced by the use of different equipment (having a higher reliability) or by introducing redundancy? (And hence what are the cost trade-offs involved?)

- What type and number of men and equipment will be needed to carry out the overall repair function?

It is intended that the model be available for use by development teams, to test the implications of changes in their proposed systems. There is considerable benefit in team members actually running the program themselves, as much can be learnt from a 'trial and error' method of working. The RPT Computer (a PRIME 400) and assistance with the program are available on request.

2 WHAT IS MEANT BY AVAILABILITY

Technically the term availability refers to the proportion of time for which a component is functioning. For wave energy, however, this is not a very useful measure. Down-time of components in winter has a more serious effect on output than that occurring in summer. Thus for our purposes we use the term system availability (S.A.), which is taken to mean the ratio of the energy produced by a system to that which would be produced if all its components always functioned.

The availability of a component is a function of two basic variables; its failure rate and the time taken to repair it. Thus the avilability of a component can be expressed as:

$$A = (1 + fr)^{-1}$$

where f = failure rate
r = repair time

The variable r, however, is itself a function of other variables. It consists of three elements; the 'live repair' time, the delay by inclement weather and the delay caused by having to queue for repair resources. Both of the latter elements vary throughout the year. Similarly it can be argued that f is in many cases a function of the weather climate, therefore, also varies in a seasonal fashion.

3 THE AVAILABILITY MODEL

In order to be able to handle the complications mentioned above in a realistic fashion, it is necessary to use a simulation model rather than an analytical one. The way that this is done is simply to reproduce, within a computer, the activities which occur in a real system and to collect statistics on the resulting performance.

Figure 3.1 shows an outline of the model, and figure 3.2 how this is translated into a computer program.

At the start of a run the system is initialised. All the repair teams are set as 'available', and the first times of failure for each unit and each mode are generated. When a unit fails, its efficiency of producing or transmitting power is adjusted. It is placed in the queue for repair, if this efficiency is low enough to warrant it. The queue of jobs to be done is scanned and available repair teams (of the right type) allocated on a priority and efficiency basis, i.e. units with a high priority and a low efficiency are repaired first. The time taken to do the repair depends upon the 'live' repair time associated with the failure type and the sea-state weather windows. When the repair is complete the next failures are generated and the process continues.

While the above is going on, changes in the sea-states are being generated. If access is not possible due to high seas the repair operation is obviously delayed. Similarly, the output power changes with the sea-state and this, coupled with the efficiency of units, is used to calculate at each point in time, the potential and landed power, and hence the lost energy due to breakdowns and the system availability.

FIG 3.1 AN OUTLINE OF THE AVAILABILITY MODEL

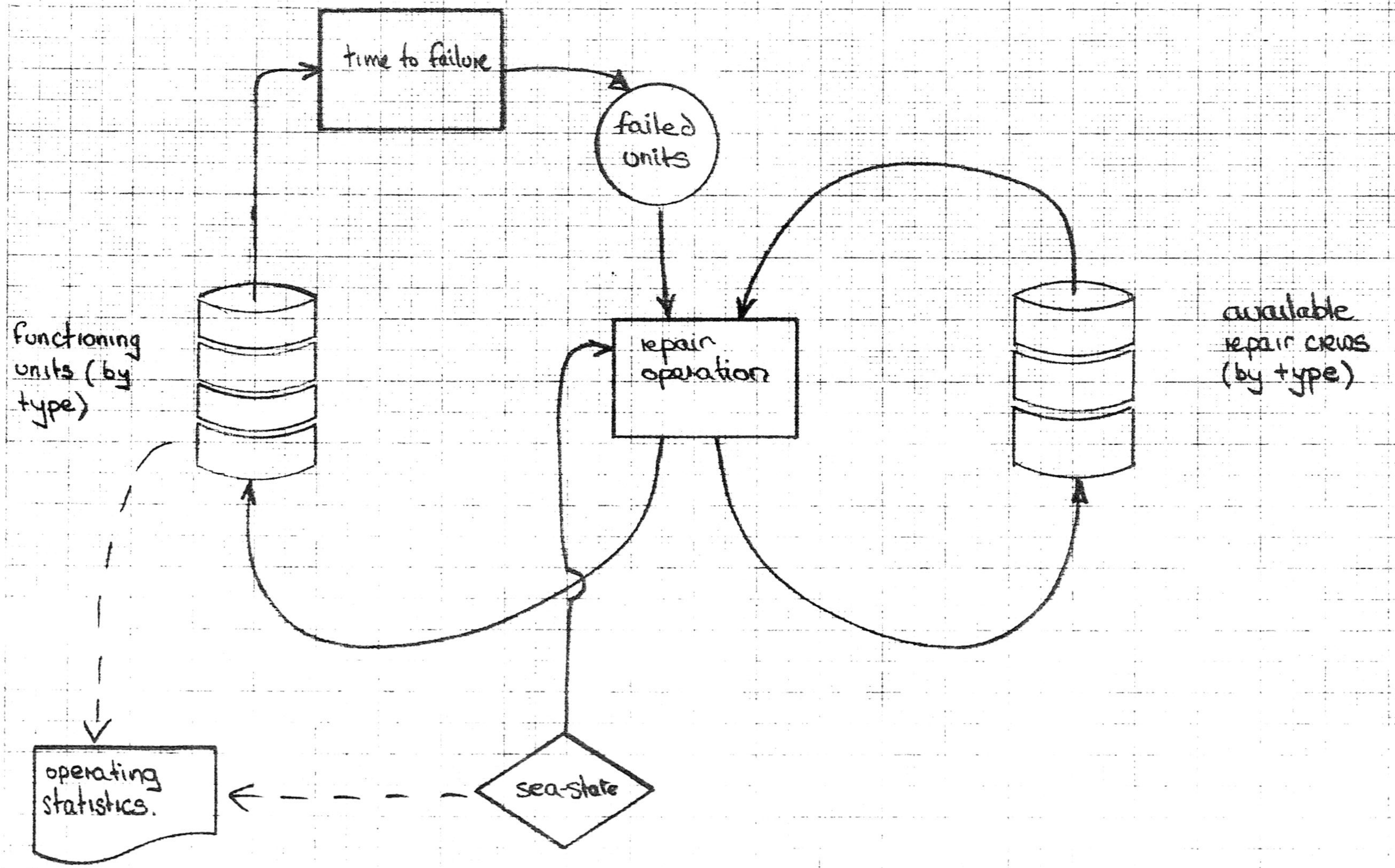
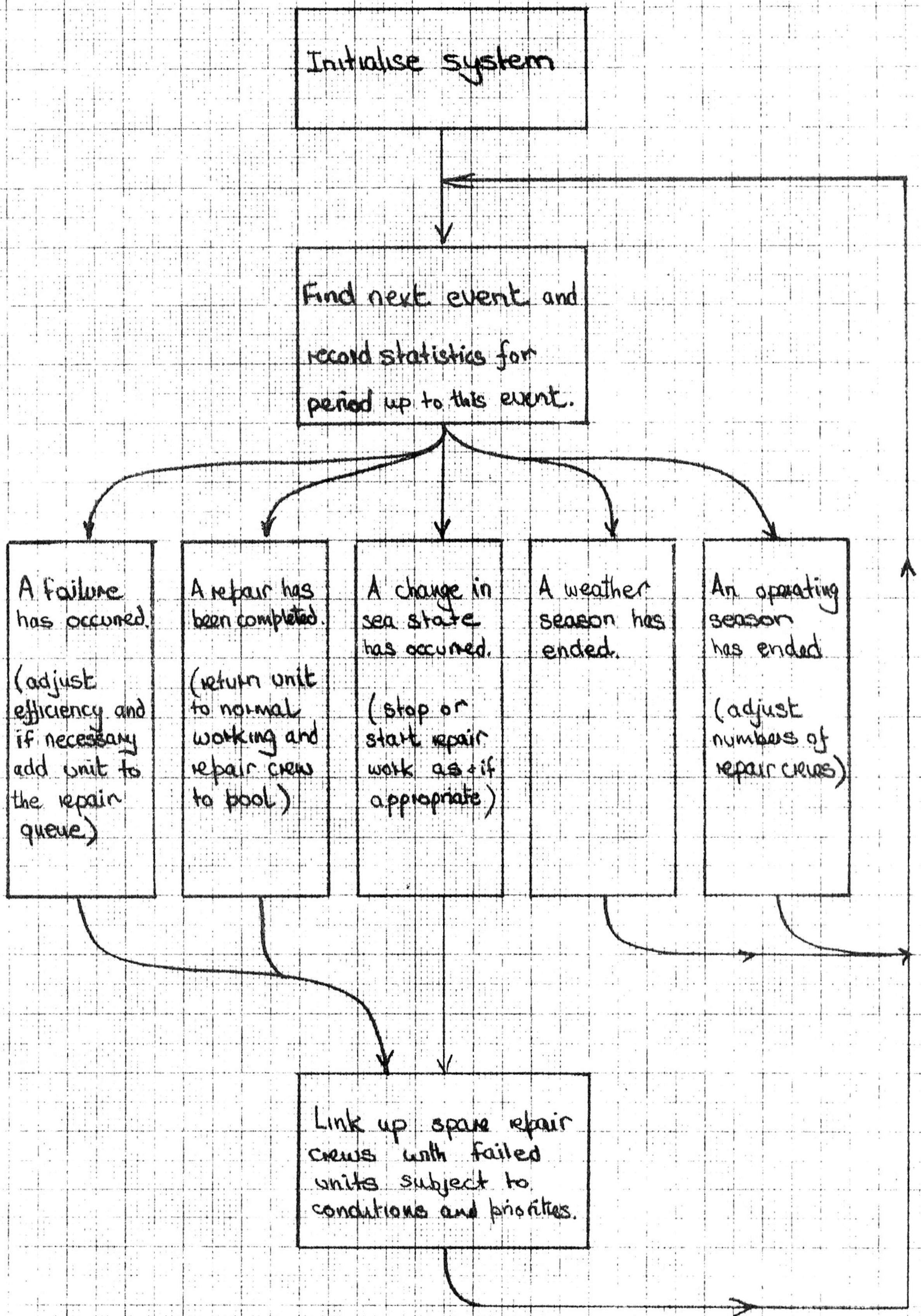


FIG 3.2. THE COMPUTER PROGRAM



4 INPUT TO THE PROGRAM

For each type of unit the following information is required:

- The number of units.
- The maximum sea-state for access and repair.
- Their priority.
- The efficiency level below which they warrant repair.
- The minimum duration of useable weather windows.
- The type(s) of repair team that can be used.
- The mean time between failures.) by
- The mean live repair time. > failure
- The efficiency after a failure.) mode

For each type of repair team:

- The number of teams for each prescribed season.

For each 'weather' season: - The Markov transition matrix of sea-states.
- The seasonal factor to be applied to failure rates.

APPENDIX B THE SEA-STATE DATA

1 INTRODUCTION

The sea-state data has been re-analysed using additional information and more thorough statistical techniques. The results given here supersede those presented in Working Paper 24.

2 THE ANALYSIS

2.1 How should the year be divided into homogeneous seasons?

Figures 1-4 show all the available sea-state data set out on an annual basis. There are two fairly complete years and two less so. The data is summarised in Figure 5 where the monthly average wave heights are plotted.

There appears to be a distinct summer season between May and August (inclusive). April and September are sometimes consistent with the summer months and sometimes with the winter ones. They have therefore been placed in a class of their own to represent 'spring' and 'autumn'. From October to March the wave heights are higher, with the apparent exception of February. This is assumed to be a statistical quirk and a single winter season of six months duration is taken. Thus we have:

April - 'spring'
May - August - 'summer'
September - 'autumn'
October - March - 'winter'

These divisions are used for the remaining analysis.

2.2 Are the sea-state durations Markovian?

Figures 6 and 7 show a comparison between the actual durations of periods with Hs less than, and greater than, 3m; and the distribution you would expect given a Markovian model. The actual durations were taken for the 'winter' of the two years where a reasonably continuous record was available. Missing points were interpolated.

The two curves can be seen to be close and so the Markov assumption was taken as reasonable.

2.3 The transition matrices

Tables 1, 2 and 3 show the number of transitions occurring between states using all the available data divided as described in Section 2.1.

2.4 Summary Table

As in Working Paper 24, a summary has been produced showing the average durations of sea-state periods. This is given in Table 4.

It will be seen that choosing more homogeneous seasons has the effect of increasing the difference in results between seasons. Formerly these were obscured by the more arbitrary divisions used.

2.5 Other Aspects of Weather

It has been suggested that sea-states on their own do not represent all the adverse weather periods that will hamper repair operations. Wind and fog should also be considered.

While wind and sea-states are highly correlated variables, fog is obviously not, as reduced visibility tends to occur with calmer winds. Easams gave a figure of about 10 days per annum when visibility was less than 5km. These were fairly evenly distributed throughout the year.

In general, therefore, our estimates of access periods may be on the optimistic side. In addition it is worth noting that we are assuming that access is possible in darkness. For some devices this may be difficult.

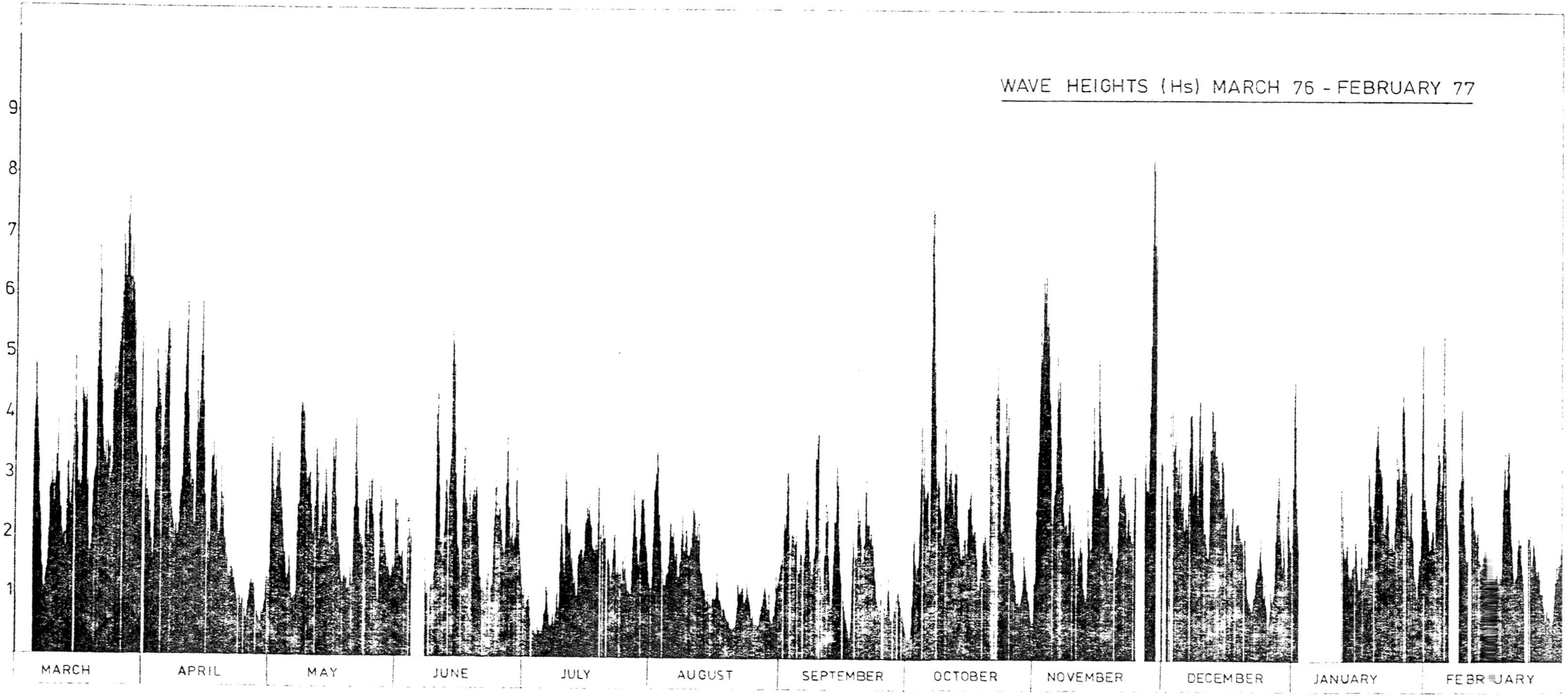
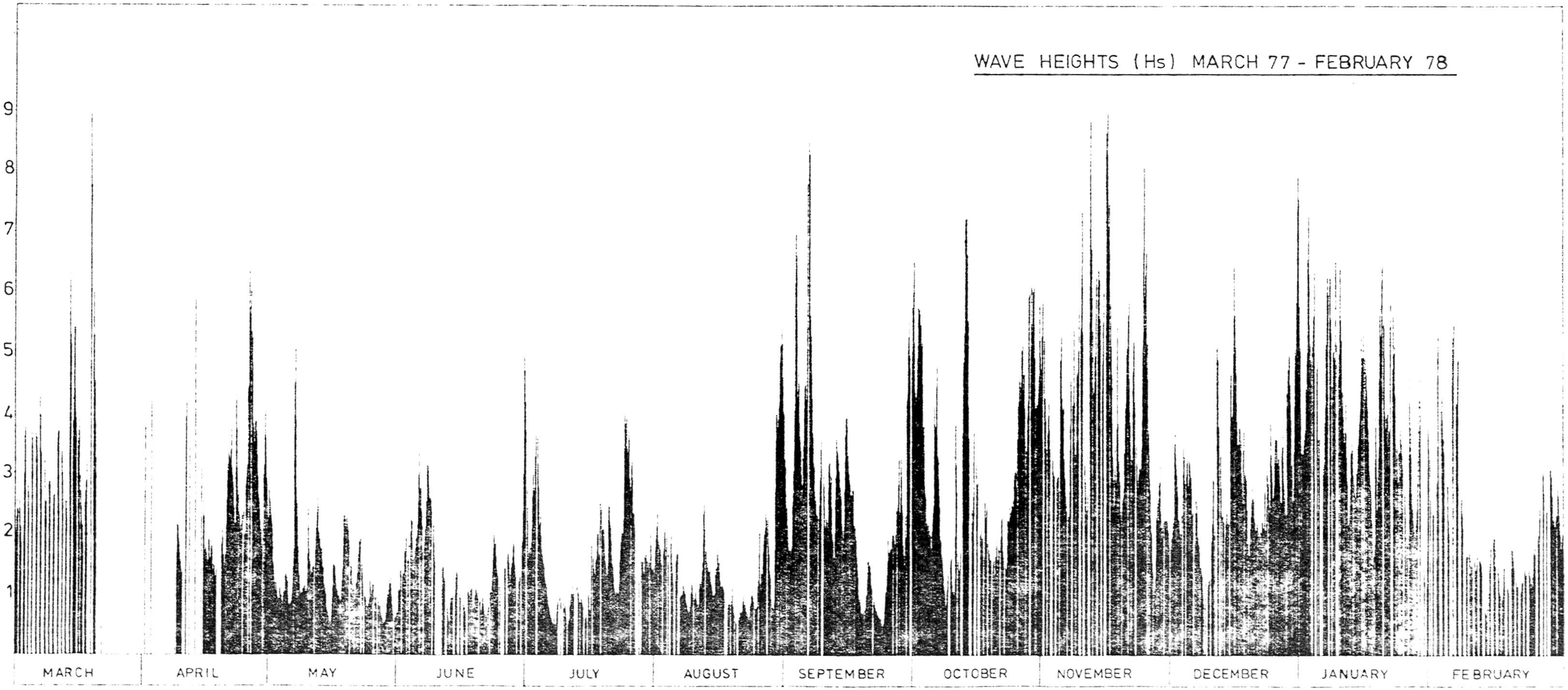
WAVE HEIGHTS (Hs) MARCH 76 - FEBRUARY 77
9
8
7
6
5
4
3
2
1
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY

FIG. 1.


WAVE HEIGHTS (Hs) MARCH 77 - FEBRUARY 78
9
8
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6
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MARCH
APRIL
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JANUARY
FEBRUARY

FIG. 2.

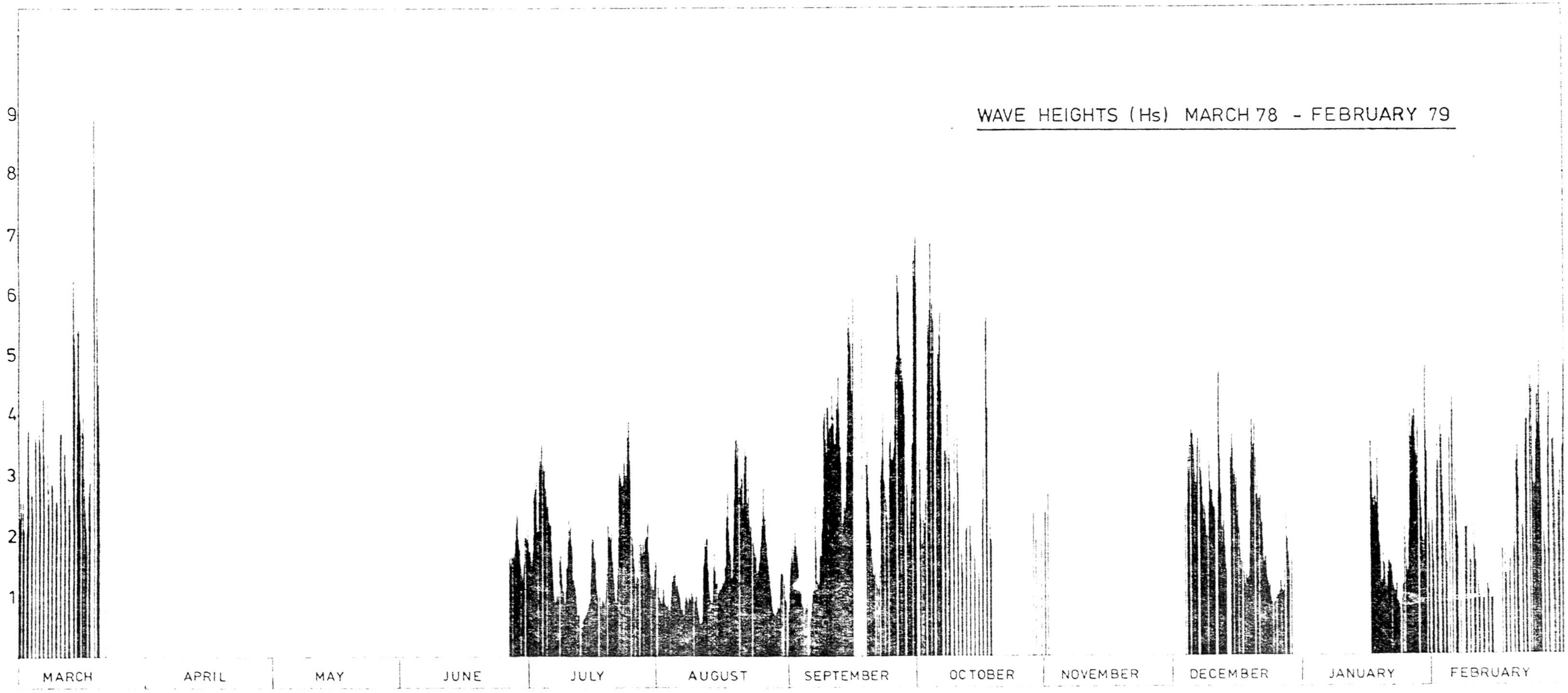
WAVE HEIGHTS (Hs) MARCH 78 - FEBRUARY 79
9
8
7
6
5
4
3
2
1
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY

FIG. 3.

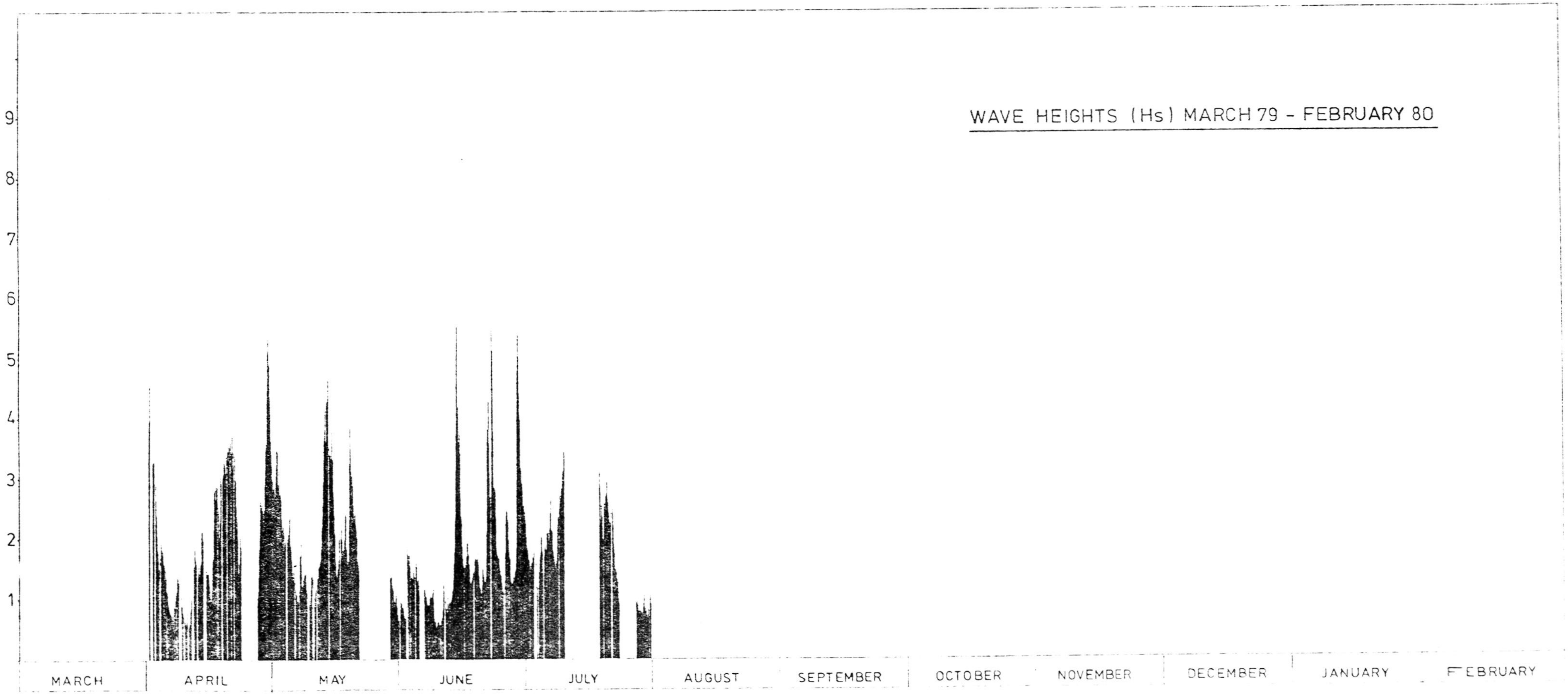
WAVE HEIGHTS (Hs) MARCH 79 - FEBRUARY 80
9
8
7
6
5
4
3
2
1
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY

FIG. 4.

Fig5 Average Wave Height Throughout the Year

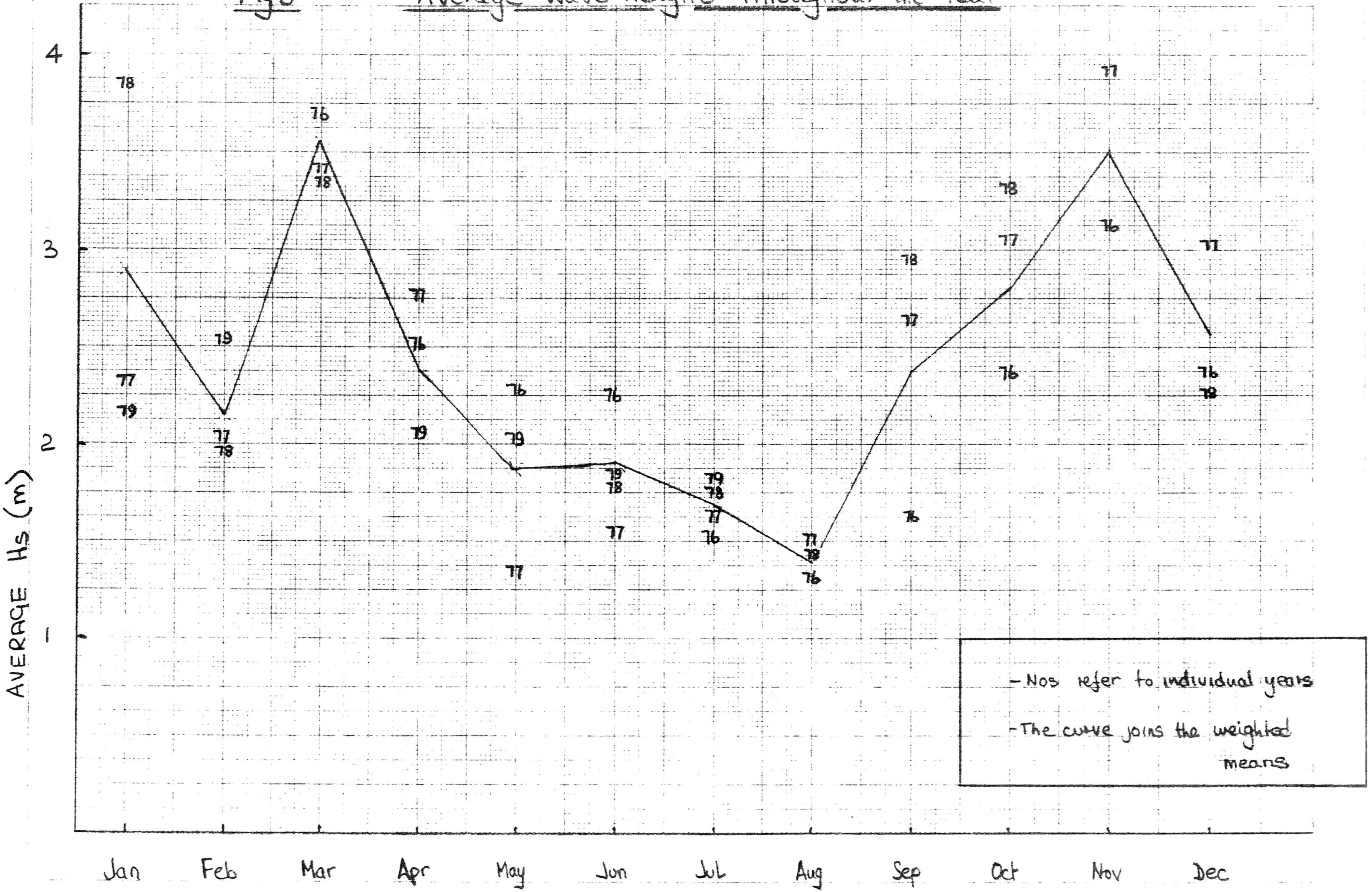

Fig 6 Durations of fine weather periods

- comparison between observed and calculated distributions (assuming a Markov model)

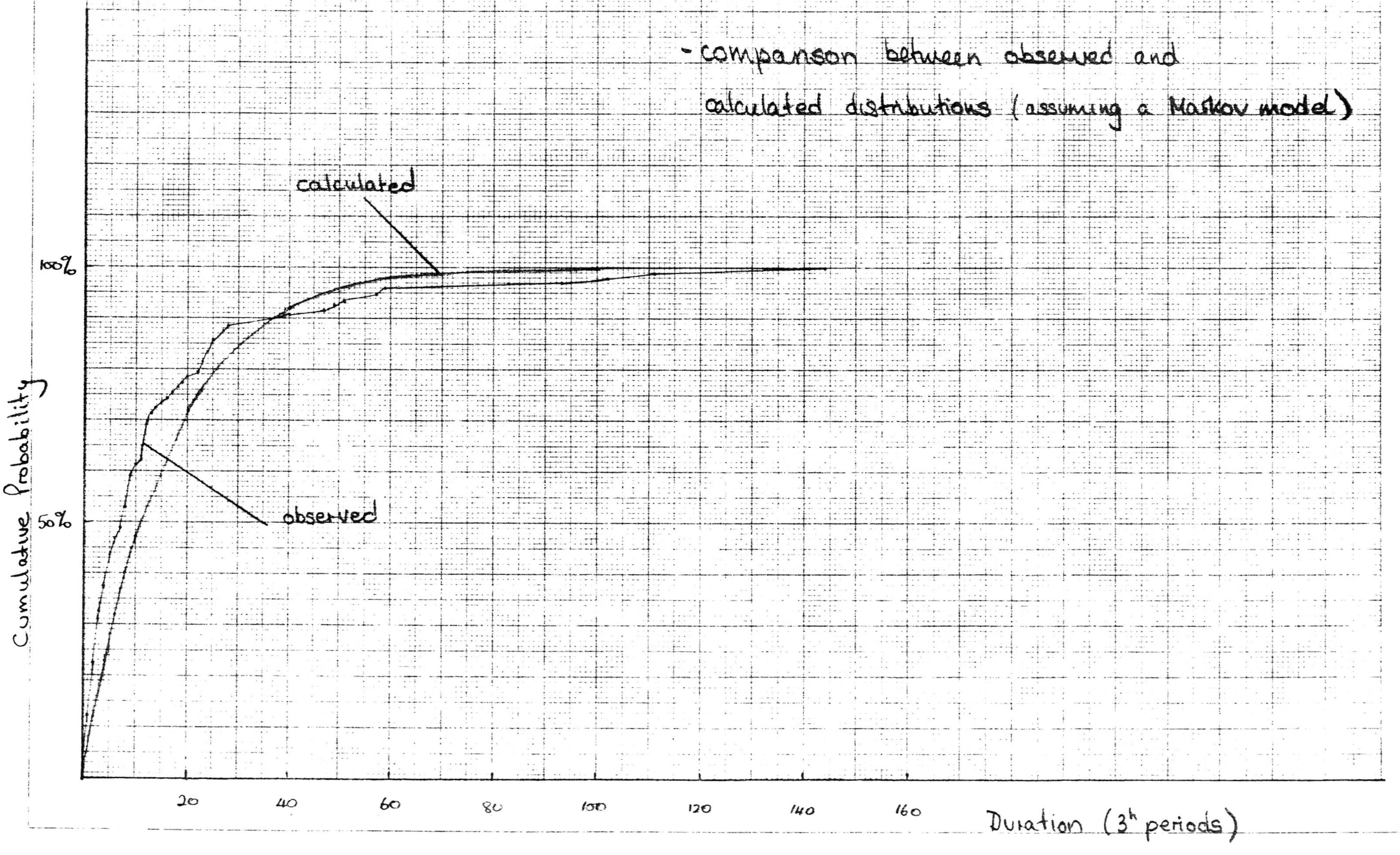

Fig 7. Durations of adverse weather periods.

- comparison between observed and calculated distributions (assuming Markov model)

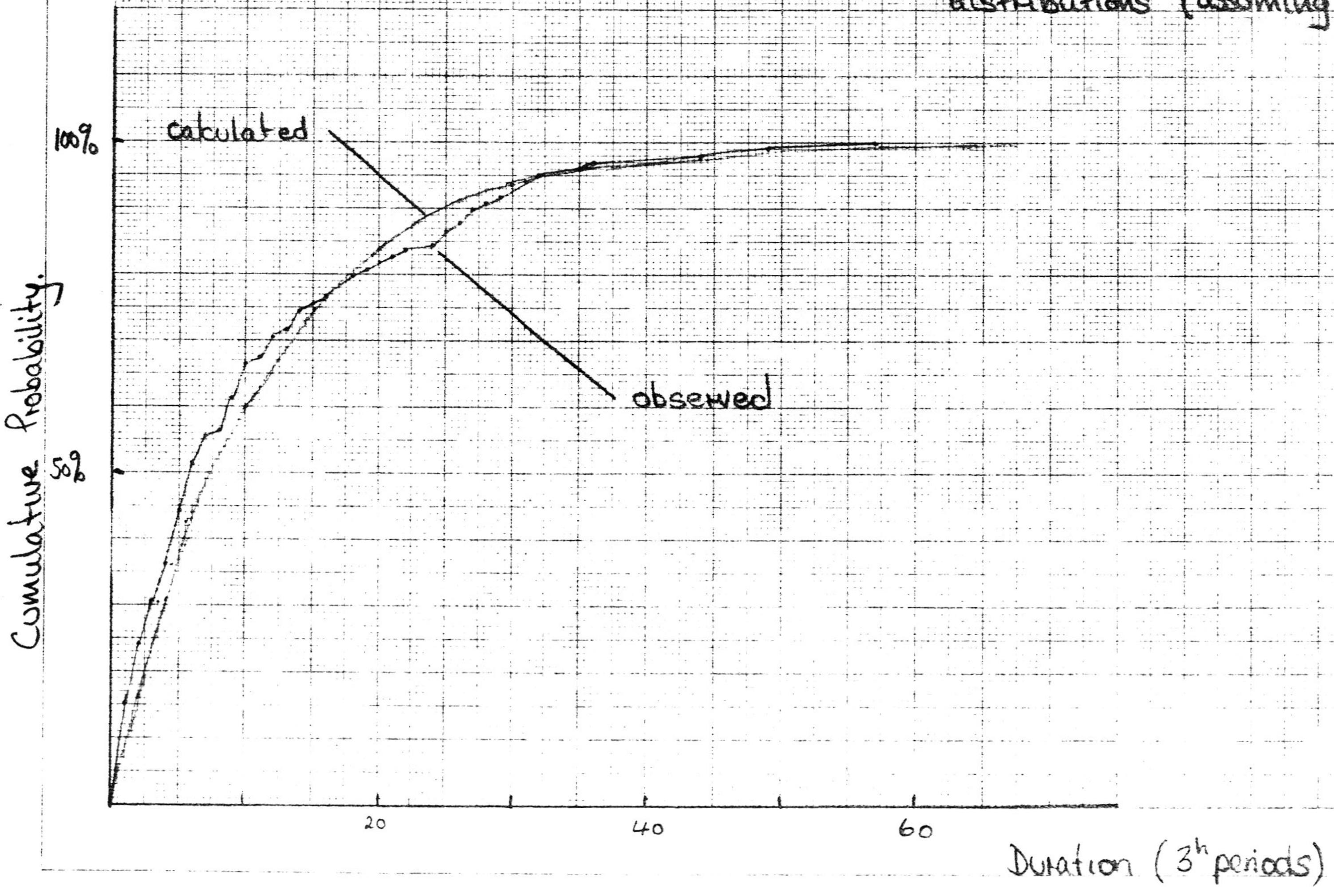

TABLE 1

TRANSITION MATRIX OF SIGNIFICANT WAVE HEIGHT

MAY - AUGUST (INCLUSIVE)

SUCCEEDING WAVE HEIGHT (M)

PRECEEDING WAVE HEIGHT (M)	0 TO 1	1 TO 2	2 TO 3	3 TO 4	4 TO 5	5 TO 6	6 TO 7	7 TO 8	8 TO 9	9 TO 10
0 TO 1	452	78	1	0	0	0	0	0	0	0
1 TO 2	78	996	78	1	0	0	0	0	0	0
2 TO 3	0	79	345	41	0	0	0	0	0	0
3 TO 4	1	0	41	85	7	0	0	0	0	0
4 TO 5	0	0	0	6	13	4	0	0	0	0
5 TO 6	0	0	0	1	3	3	0	0	0	0
6 TO 7	0	0	0	0	0	0	0	0	0	0
7 TO 8	0	0	0	0	0	0	0	0	0	0
8 TO 9	0	0	0	0	0	0	0	0	0	0
9 TO 10	0	0	0	0	0	0	0	0	0	0

TABLE 2

TRANSITION MATRIX OF SIGNIFICANT WAVE HEIGHT

APRIL AND SEPTEMBER

SUCCEEDING WAVE HEIGHT (M)

PRECEEDING WAVE HEIGHT (M)	0 TO 1	1 TO 2	2 TO 3	3 TO 4	4 TO 5	5 TO 6	6 TO 7	7 TO 8	8 TO 9	9 TO 10
0 TO 1	168	18	0	1	0	0	0	0	0	0
1 TO 2	19	296	34	3	1	0	0	0	0	0
2 TO 3	0	37	238	34	1	0	0	0	0	0
3 TO 4	0	1	38	131	24	2	0	0	0	0
4 TO 5	0	1	0	23	47	14	4	0	0	0
5 TO 6	0	0	0	4	16	23	3	1	0	0
6 TO 7	0	9	0	0	0	7	5	0	0	0
7 TO 8	0	0	0	0	0	0	0	0	1	0
8 TO 9	0	0	0	0	0	1	0	0	0	0
9 TO 10	0	0	0	0	0	0	0	0	0	0

TABLE 3

TRANSITION MATRIX OF SIGNIFICANT WAVE HEIGHT

OCTOBER - MARCH (INCLUSIVE)

SUCCEEDING WAVE HEIGHT (M)

PRECEEDING WAVE HEIGHT (M)	0 TO 1	1 TO 2	2 TO 3	3 TO 4	4 TO 5	5 TO 6	6 TO 7	7 TO 8	8 TO 9	9 TO 10
0 TO 1	83	22	0	2	0	1	0	0	0	0
1 TO 2	21	646	92	10	0	0	0	0	0	0
2 TO 3	0	101	677	117	5	4	0	0	0	0
3 TO 4	2	0	133	390	66	6	0	1	2	0
4 TO 5	1	0	2	75	140	41	5	0	0	0
5 TO 6	0	0	0	5	53	77	24	2	0	0
6 TO 7	0	0	0	1	1	28	23	5	3	0
7 TO 8	0	0	0	0	0	3	8	9	1	0
8 TO 9	0	0	0	0	0	1	1	4	5	0
9 TO 10	0	0	0	0	0	0	0	0	0	0

TABLE 4

Durations of adverse and fine weather periods.

SEASON	Limiting Hs=2m		Limiting Hs=3m		Limiting Hs=4m	
	T1(hrs)	T2(hrs)	T1(hrs)	T2(hrs)	T1(hrs)	T2(hrs)
spring - autumn	42	51	64	26	112	16
summer	63	24	150	12	978	13
winter	25	59	39	24	56	19

T1 - Mean time between periods of adverse weather (i.e. periods when Hs was less than the limiting value).

T2 - Mean time between periods of fine weather (i.e. periods when Hs was greater than the limiting value).