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SPRINKLER PERFORMANCE FOR FROST PROTECTION SYSTEMS

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CONTENTS

ABSTRACT

Frost protection using overhead sprinkler systems has become increasingly important in New Zealand horticulture since the mid-1970's. The reasons for this change and the problems created by the rapidity with which it occurred have been examined.

The design requirements of sprinkler frost protection systems are considered. A performance parameter which is based on the percentage of the area receiving less than the minimum application rate necessary to achieve protection is introduced. Sprinkler performance can be measured by still-air distribution pattern tests and the resulting information can be used with computer programmes to predict system performance. The way in which these tasks have been done is described before presenting the results of many such analyses. This information should be of considerable benefit to designers of frost protection systems in New Zealand.

ACKNOWLEDGEMENTS

Still-air sprinkler testing, which provided the data on which much of the work reported here is based, is a tedious job carried out in not particularly pleasant conditions. The author wishes to thank those Institute technicians who willingly shared the burden of this work.

Thanks must also go to Dr Errol Hewett, Plant Diseases Division, DSIR, whose enthusiasm and valued advice during the early stages of this project were appreciated. Thanks also to the many M.A.F. advisory officers in agricultural engineering whose interest and requests for endless information made this report possible, and to John Baird who, during the latter part of this work, assisted with much of the computing.

1. INTRODUCTION

Since the mid 1970's there has been a dramatic change in the methods used for frost protection of horticultural crops in New Zealand. Prior to the oil-price spiral the great majority of frost protection systems used oil-burning frost pots. Now these have almost entirely been replaced by overhead sprinkler systems. The change to sprinkler systems occurred rapidly and caused system designers, contractors and growers some problems. The requirements of a frost protection system are stringent, requiring relatively low application rates together with high levels of uniformity and at the same time being constrained by sprinkler layouts which have to match existing tree spacings and orchard layouts. In an attempt to assist with these problems the Institute undertook a programme of sprinkler testing. The results obtained were then used in a computer overlapping programme to provide the necessary performance information.

This report describes the background to this work, gives an outline of the theory of frost protection by sprinkling and presents in summary form the results of the analyses carried out to date.

2. BACKGROUND

Protecting crops against damaging late spring frosts has always been a problem for horticulturists in New Zealand, and particularly so for the orchardists in the Central Otago area where frost protection has been required ever since commercial operations began in the 1930's.

Prior to about 1974 virtually all frost protection was carried out using oil-fired orchard heaters although a few growers were using overhead sprinkler systems. Sprinkler methods had also been under investigation since the mid-1960's by the DSIR Plant Diseases Division at their research orchard at Earnscleugh. The results of this work demonstrated that overhead sprinkler systems could cope with most of the frost conditions experienced in Central Otago and established the basic design parameters relating to application rates and rotation times. The foresight of those involved in this work became evident in 1973, which saw the beginning of a continuous sequence of price rises and shortages of oil. It soon became apparent that oil-fired orchard heating systems would no longer be economic and growers were able to turn to overhead sprinkler systems with the knowledge that this method had been proved successful under New Zealand conditions.

By 1976 a considerable number of growers had installed sprinkler systems in Central Otago. There was concern, however, that the performance of some of the installed systems was not up to the standard expected. At this time the Institute was approached by both the M.A.F. Advisory Services Division and the DSIR Plant Diseases Division to see if it could assist in resolving some of these problems.

During the early part of this study it became apparent that the biggest problem was the lack of appreciation by growers, designers and contractors of the importance of uniformity of water distribution. Although most systems were applying the required average application rate, sprinkler spacings were, in some cases, so great that the resulting distribution pattern would not provide adequate protection over the whole area. Our initial approach was therefore to demonstrate the importance of uniformity and to provide advisory staff with performance data for the various combinations of sprinklers and spacings then in use.

As frost events usually occur under near-calm conditions it was felt that sprinkler performance data collected under still-air conditions could reasonably be used to predict system performance. A programme of sprinkler testing was undertaken using the various types of sprinkler, nozzle sizes and operating pressures in common use in the Central Otago area. The performance of these sprinklers at various spacings was then estimated by using a computer overlapping technique to calculate, from the still-air distribution patterns, the probable overlapped distribution pattern.

Since this initial work in 1976 the horticultural industry has undergone considerable expansion both in terms of the areas being developed and the type of crops being grown. In many cases the installation of frost protection systems has been considered an essential part of this development and this has resulted in continued requests for performance data for different sprinklers, and in particular, different spacings.

As a consequence of these requests a considerable amount of estimated performance data for a range of sprinklers, nozzle sizes, pressures, and spacings has been collected. The major function of this report is to summarise this information so that it becomes more readily available to designers of frost protection systems.

3. THEORY OF OPERATION OF OVERHEAD SPRINKLER FROST PROTECTION SYSTEMS

The particular factor that makes it possible to protect crops from frost damage by sprinkling with water is the large amount of heat which is released when water changes from a liquid to a solid. When a cubic metre of water is cooled by one degree Celsius, 1.2 kWh of energy is released. This amount of energy is released for every degree of cooling that takes place until the temperature reaches zero. At this point a very much larger amount of energy is released as the water undergoes a change of stage from a liquid to a solid. In fact about 93 kWh of energy is released when one cubic metre of water changes from a liquid at $0^{o}C$ to ice at the same temperature. It should be noted that as far as frost protection is concerned the initial temperature of the water is of little consequence, as a relatively very small amount of energy is made available from the cooling of the water in comparison with that made available from the change from liquid water to ice. The objective of a sprinkler frost protection system is therefore to maintain a film of water over the particular organs of the plant to be protected. Even if a layer of ice forms, the temperature of the ice and the plant tissue inside it will not fall appreciably below zero as long as the surface of the ice is kept wet.

The factors involved in maintaining a film of water over the whole plant structure are complex. The amount of water applied must be such as to provide sufficient heat release to prevent the temperature falling below the critical level. At the same time the plant is only capable of "holding" a certain amount of water and this will vary, depending on the type of plant, the particular stage of growth and the way in which the water is applied. Ideally the water would be supplied continuously and at a rate just exceeding that required to release enough heat energy to keep crop temperature above the critical value.

This concept has been adopted on an experimental basis by using small spray nozzles mounted above each tree. In the field situation however, this is not very practical because of the large amount of pipework required. Instead, conventional impact-drive sprinklers are used. Because of the intermittent nature of the application made by these sprinklers two factors are very important, the application rate, and the sprinkler rotation time. If insufficient water is applied or the time interval between applications is too long, all the water applied in one application (rotation) will freeze and the temperature may drop below the critical value before the next application is made.

At first sight it may appear that the rotation time is self-compensatory in that the slower the rotation rate the more water is applied per revolution. This overlooks the question of how much water can be "held" on the foliage and branches of the tree. Once the tree or plant is "full" any further application of water will just run off and be wasted. The balance between rotation rate and application rate is therefore very important. Research in both New Zealand and overseas indicates that rotation times in the range of 30 to 60 seconds provide adequate performance with the upper limit being considered an absolute maximum. (Hewett, 1971; Wolfe, 1969).

Although it would be desirable to be able to vary the application rate to match the prevailing conditions this is impractical with conventional sprinkler systems which must, therefore, be designed to cope with the most severe conditions likely to be encountered. Table 1 lists suitable average application rates which may be used for design purposes. Hewett (1971) suggests that for Central Ogato conditions an average rate of 3.8 mm/hr should be adequate while for less frost-susceptable areas, say from Canterbury northwards, this figure could be reduced to 3.0 mm/hr.

TABLE 1

Suggested average application rates for overhead sprinkler frost protection systems. (After Hewett, 1971).

Deciduous Fruit Trees

Application rate mm/hr	2.5	3.0	3.8	4.6	6.4
Minimum temperature, screened thermometer °C	-2.2	-3.3	-4.2	-4.7	-5.8
Approx. minimum temperature, exposed thermometer. °C	-3.3 to 3.9	-4.4 to -5.0	-5.3 to -5.8	-5.8 to -5.7	-6.9 to -7.8

Low-Growing Crops

Application rate mm/hr	2.5	3.0	3.6	4.6
Minimum temperature, screened thermometer °C	-2.2	-3.3	-5.0	-6.7
Approx. minimum temperature, exposed thermometer. °C	-3.3 to -3.9	-4.4 to -5.0	-6.1 to -6.7	-7.8 to -8.3

Note: A screened thermometer is one that is arranged so that it is not exposed directly to the sky. For a description of temperature measurement in orchards and for further details regarding the above Table readers are referred to Hewett, 1971.

It must be emphasised however that these average application rates will provide protection only if the application is *uniform*. It is not always easy to achieve high levels of uniformity with the relatively low application rates required, especially when sprinkler and lateral spacings are constrained by tree spacings. In addition there is no easy way of assessing the reduction in frost protection performance due to a given reduction in uniformity. This problem has led the Institute to adopt the concept of the *minimum* application rate necessary to provide adequate protection as a performance parameter. The use of this parameter has been made possible by the use of the computer overlapping programme described briefly in Section 4 which enables the percentage of the area receiving less than or equal to any given application rate to be determined very easily. Sprinkler systems can therefore be assessed on the basis of the percentage of the area not likely to receive adequate protection, a more meaningful parameter than some sort of uniformity coefficient.

The only problem in developing this approach was in deciding on suitable values for the minimum application rate as most of the available research results are expressed as average application rates. By assuming that a statistical normal distribution adequately describes the population of intensities produced under a sprinkler system, Hart and Reynolds (1965) showed how the application rate equalled or exceeded over any given percentage of the sprinkled area, could be calculated for a given average application rate and a given value of Christiansen's Uniformity Coefficient. (see Appendix C for a description of this parameter). This technique was used to determine the probable *minimum* application rates occurring under systems having the *average* application rates contained in the previous recommendations. In doing this it was assumed that the frost protection systems used for the research trials applied the water uniformly (Christiansen's uniformity coefficient of 80%) and were attempting to obtain almost complete protection (over at least 90% of the sprinkled area). Using this technique it was found that for an average application rate of 3.8 mm/hr and a uniformity coefficient of 80%, at least 90% of the area would receive an application rate of 2.5 mm/hr or more. Similarly, but for an average application rate of 3.0 mm/hr it was found that 90% of the area would receive 2.0 mm/hr or more.

These calculations suggested that where an average application rate of 3.8 mm/hr had been recommended a *minimum* rate of 2.5 mm/hr is required to achieve adequate protection and where an average of 3.0 mm/hr had been recommended a *minimum* rate of 2.0 mm/hr is required. These two values have been adopted as minimum design rates and the performance data presented in the Appendices includes the percentage of the sprinkled area receiving application rates less than or equal to these two values, that is, the percentage of the area likely to receive inadequate protection. It is suggested that this parameter is one of the more important factors to be used in deciding on the adequacy of a particular layout.

The final factor of considerable importance in frost protection design relates to nozzle pressure. The ability of the spray to "wet" a tree or plant will depend largely on the drop sizes produced. A few large drops will be much less effective than the same volume applied as a large number of small drops. While the internal configuration of the actual sprinkler will have some influence on drop size distribution the most important factors are nozzle size and operating pressure. For the relatively small nozzles commonly used for frost protection systems (3.5 - 5.0 mm) adequate performance (for frost protection) should be obtained at pressures of about 400 kPa. A pressure of 350 kPa should be considered a minimum (Pillsbury and Degan, 1968; Hewett, 1971). If for any reason larger nozzles are used consideration should be given to operating them at higher pressures than those suggested.

4. TESTING AND ANALYSIS

Because frost events are associated with calm conditions it is possible to use still-air test data to perdict system performance. This has the advantages that tests can be conducted indoors under standard conditions, testing can be carried out regardless of the weather conditions and errors due to evaporative losses from the catch-cans are negligible. The results of such tests are expressed as a still-air, intensity distribution pattern such as is shown in Figure 1.

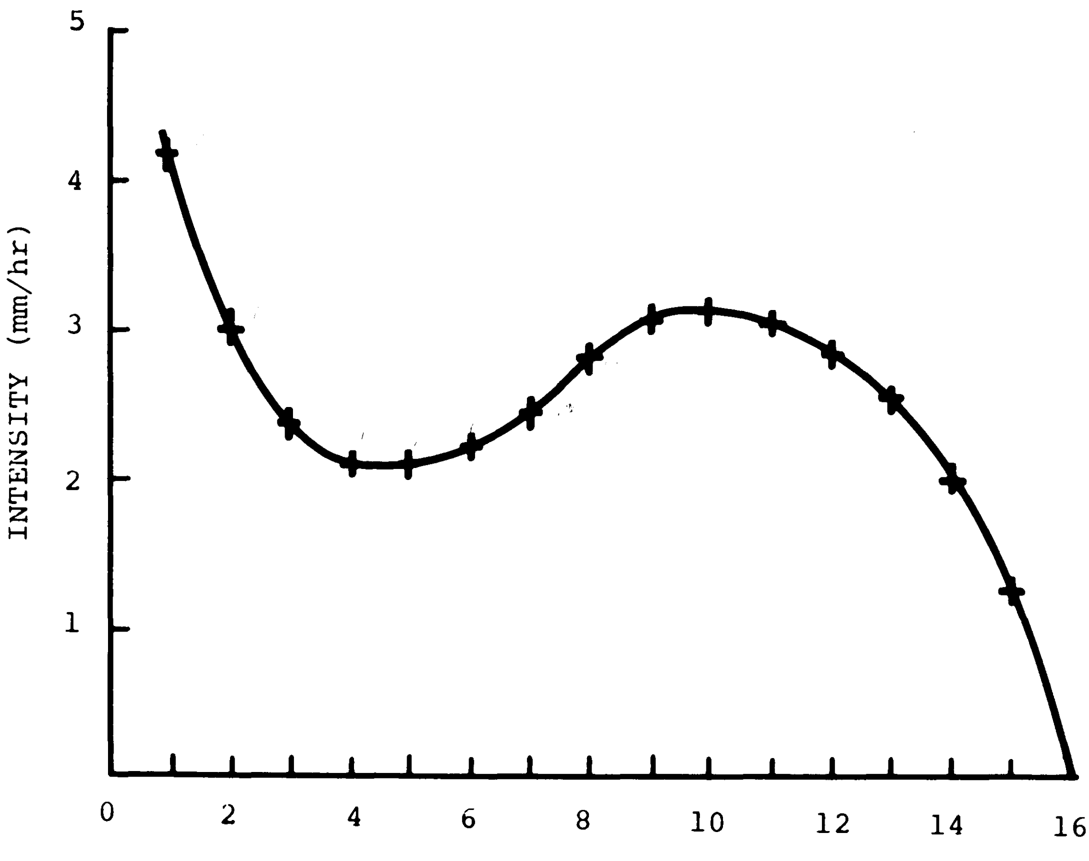

Figure 1. A typical still-air intensity distribution pattern

Still-air test data such as these are subsequently analysed using a computer programme which has the following three main functions: it overlaps the single sprinkler pattern to predict the distribution pattern that would have been produced had the sprinkler been operated in a complete system; it calculates from the distribution pattern various parameters which characterise system performance; and it presents this information in a manner most likely to be of value to the user. The programme can analyse either rectangular or triangular (equilateral only) layouts, and up to twelve different spacings can be examined in any one run. The full output from each sprinkler/spacing/layout combination includes:

(i) the mean, minimum and maximum intensity values,
(ii) several uniformity coefficients,
(iii) a histogram and cumulative frequency distribution of the intensities within the over-lapped pattern,
(iv) a listing of the actual intensities within the over-lapped area, and
(v) a scale contour diagram of the distribution pattern showing contours of equal application rate.

Note that the cumulative frequency distribution enables the percentage of the area receiving less than or equal to any given application to be determined by reading the required values off the computer drawn graph.

A more detailed description of the computer programme and sprinkler testing procedure has been given by Carran (1981).

5. PRESENTATION OF THE DATA AND THEIR LIMITATIONS

5.1 THE DATA

To publish the complete set of output data from every computer run is impractical. Instead those results which are considered to be of most use to system designers have been summarised. Six basic performance parameters have been listed for each combination of sprinkler type, nozzle size, pressure, spacing and layout. These parameters are:- the mean, maximum, and minimum intensities in mm/hr, Christiansen's Uniformity Coefficient and the percentage of the sprinkled area receiving intensities of less than or equal to 2 mm/hr and 2.5 mm/hr.

These summaries are appended to this report under two major sub-divisions according to whether the layout is rectangular (Appendix A) or triangular (Appendix B). In each case the data have been arranged in order of sprinkler type (alphabetically by name), nozzle size and pressure, (Tables A1 and B1). In addition, an index based on spacing has also been prepared for each of the two layout groupings (Tables A2 and B2). The convention used throughout the results to describe sprinkler spacing uses the order: spacing between sprinklers by spacing between laterals. Because still-air sprinkler distribution patterns are symmetrical however, it is not necessary to adhere to this convention. This is, a 12 m by 18 m spacing will have the same performance characteristics as an 18 m by 12 m spacing.

5.2 LIMITATIONS

There are some limitations in the data presented and it is very important that anyone using this information takes these into account. Some of the problems are due to the way in which information has been derived. As has been pointed out in Section 3 the results essentially summarise the findings of a series of extension projects, rather than representing the findings of an exhaustive survey of frost protection sprinkler performance. Some omissions of sprinkler types and spacings are bound to have occurred because of this.

Another problem concerns data inadequacies, particularly in relation to rotation times. In some cases requests have been received for performance information for sprinklers which have been tested for normal irrigation purposes only, and the rotation times will therefore be considerably slower than those considered optimum for frost protection. While the analyses of these tests have been included in the summaries they should be treated with caution. Changing the rotation speed of a sprinkler appreciably can change the distribution pattern and hence the resulting system performance prediction.

It should also be remembered that the results strictly apply only to a horizontal plane about 500 mm below the level of the sprinkler nozzle. This corresponds to the plane of the collection cans used in the original still-air tests. In most frost protection systems the sprinklers are mounted on risers four to five metres above ground level and therefore the horizontal surface over which the results apply will be three and a half to four and a half metres above the ground. This generally corresponds to about the upper third of a mature tree canopy.

In summary, anyone using the data contained in the Appendices should carefully consider the following very important points.

(a) The absence of a particular sprinkler and/or pressure, nozzle size, spacing combination does not imply that it may not perform as well as those published.

(b) Care should be taken in using performance data based on sprinkler tests where the sprinkler rotation time is appreciably different from the intended rotation time.

(c) Small differences (less than 5%) between performance figures cannot be regarded as significant.

(d) The performance figures published in this report apply to a horizontal plane approximately 500 mm below the sprinkler nozzle.

(e) The data provided for a given sprinkler are based on the results of one test on one particular sprinkler body. How this performance compares with the *average* performance of the same sprinkler type will depend largely on the quality control of the manufacturer.

6. REFERENCES

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APPENDIX A

PERFORMANCE DATA FOR RECTANGULAR LAYOUTS

Two tables are presented in this Appendix. The first, Table A1, summarises the performance of the sprinklers tested at various spacings. These are listed by sprinkler type (alphabetically), nozzle size and nozzle pressure. The two right-hand columns in each list show the percentage of the area receiving less than or equal to (LEQ) 2.5 mm/hr and 2.0 mm/hr respectively. It is very important that anyone using this table fully understands the limitations of the data in it. These have been described in Section 5.2 (pg 9) of this report.

Table A2 (pg 27) is an index of the data by spacing. An asterisk by a page number in this index indicates that more than one example of the spacing will be found on that page.

TABLE A1 PERFORMANCE SUMMARIES FOR RECTANGULAR LAYOUTS

SPRINKLER TYPE	BAUER B70
NOZZLE SIZE(S)	4.5 MM
PRESSURE	400 KPA
ROTATION TIME	43 SECONDS
WETTED DIA.	32.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
22.0	22.0	75	3.1	6.8	1.3	29	12
19.0	22.0	79	3.6	7.0	2.0	15	4
18.0	24.0	77	3.5	6.9	2.0	21	2
17.0	18.0	83	4.9	7.4	3.4	0	0
12.0	17.0	83	7.4	11.2	4.2	0	0
15.0	15.0	83	6.7	9.6	4.9	0	0
15.0	20.0	85	5.0	8.2	2.9	0	0

SPRINKLER TYPE	BAUER B70
NOZZLE SIZE(S)	4.5 MM
PRESSURE	500 KPA
ROTATION TIME	38 SECONDS
WETTED DIA.	32.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
22.0	22.0	81	3.6	6.9	1.0	14	7
19.0	22.0	82	4.2	7.1	2.6	2	0
18.0	24.0	78	4.0	7.0	1.7	9	2
17.0	18.0	86	5.7	7.2	4.0	0	0
12.0	17.0	88	8.5	11.3	6.4	0	0
15.0	15.0	86	7.7	10.5	6.2	0	0
15.0	20.0	89	5.8	8.1	3.7	0	0

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	D-SN75
NOZZLE SIZE(S)	4.0 MM
PRESSURE	350 KPA
ROTATION TIME	60 SECONDS
WETTED DIA.	26.4 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
18.3	18.3	66	3.1	6.4	1.6	38	22
18.3	15.2	75	3.7	6.4	1.7	20	11

SPRINKLER TYPE	D-SN75
NOZZLE SIZE(S)	4.0 MM
PRESSURE	400 KPA
ROTATION TIME	71 SECONDS
WETTED DIA.	26.4 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
20.0	15.6	73	3.5	6.4	1.8	25	10
18.0	21.3	67	2.9	6.4	0.3	45	23

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	D-SN75
NOZZLE SIZE(S)	4.5 MM
PRESSURE	350 KPA
ROTATION TIME	59 SECONDS
WETTED DIA.	26.4 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
18.3	15.2	70	4.4	7.1	1.9	20	11
19.0	20.0	63	3.2	7.1	0.3	38	22
18.5	20.8	63	3.2	7.1	0.2	39	23
18.3	18.3	62	3.7	7.1	1.4	37	20

SPRINKLER TYPE	D-SN75
NOZZLE SIZE(S)	4.5 MM
PRESSURE	400 KPA
ROTATION TIME	70 SECONDS
WETTED DIA.	28.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
20.0	20.8	56	3.4	6.6	1.3	41	28
22.0	16.5	64	3.8	7.6	0.4	26	13

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	D-SN75
NOZZLE SIZE(S)	5.0 MM
PRESSURE	400 KPA
ROTATION TIME	58 SECONDS
WETTED DIA.	26.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
20.0	20.8	64	4.2	6.6	2.0	20	10

SPRINKLER TYPE	D-SN75
NOZZLE SIZE(S)	5.0 MM
PRESSURE	550 KPA
ROTATION TIME	46 SECONDS
WETTED DIA.	32.8 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
20.0	20.8	75	5.5	8.2	2.4	8	0

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	3.4 MM
PRESSURE	400 KPA
ROTATION TIME	43 SECONDS
WETTED DIA.	26.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
20.0	15.6	75	2.8	7.6	1.2	40	14
16.5	16.5	83	3.2	7.6	2.0	20	0

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	3.9 MM
PRESSURE	400 KPA
ROTATION TIME	92 SECONDS
WETTED DIA.	31.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
18.0	18.0	73	3.5	7.2	1.1	24	17
18.0	21.3	69	3.0	4.6	1.0	31	23
14.0	28.0	76	2.9	5.1	1.0	30	14
22.0	15.0	81	3.5	6.1	1.4	17	9

TABLE A1 (cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.4 MM
PRESSURE	400 KPA
ROTATION TIME	73 SECONDS
WETTED DIA.	31.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
13.5	30.0	69	3.6	7.1	0.4	22	15
15.0	30.0	65	3.3	5.0	0.1	28	16
12.0	30.0	71	4.1	8.5	0.6	18	15
19.5	22.0	67	3.4	5.1	1.6	33	23

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.4 MM
PRESSURE	450 KPA
ROTATION TIME	79 SECONDS
WETTED DIA.	30.4 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
22.0	18.0	71	3.6	4.9	1.5	27	19
22.0	19.5	68	3.3	4.9	0.6	33	21

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.4 MM
PRESSURE	500 KPA
ROTATION TIME	85 SECONDS
WETTED DIA.	30.8 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	22.0	76	3.8	5.1	1.6	21	11
22.0	22.0	70	2.9	4.7	0.8	46	23
16.5	16.5	76	5.1	9.2	2.3	6	0

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.9 MM
PRESSURE	350 KPA
ROTATION TIME	33 SECONDS
WETTED DIA.	31.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
25.6	19.5	75	3.2	5.3	1.7	29	6

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.9 MM
PRESSURE	400 KPA
ROTATION TIME	41 SECONDS
WETTED DIA.	33.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
22.0	22.0	75	3.5	5.2	1.9	19	6
19.0	22.0	77	4.1	5.6	1.8	16	6
18.0	24.0	79	3.9	5.8	2.0	14	4
17.0	18.0	79	5.5	8.7	2.6	0	0
12.0	17.0	83	8.3	10.9	4.9	0	0
15.0	15.0	81	7.5	10.8	5.8	0	0
15.0	20.0	82	5.7	8.6	3.5	0	0
10.8	30.0	73	5.2	9.6	1.8	12	10
15.0	30.0	69	3.8	6.0	0.9	21	15
18.0	30.0	64	3.1	5.8	0.3	37	21

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.9 MM
PRESSURE	500 KPA
ROTATION TIME	41 SECONDS
WETTED DIA.	34.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
22.0	22.0	79	4.0	5.6	2.2	9	0
19.0	22.0	81	4.6	6.3	2.2	8	0
18.0	24.0	82	4.5	6.5	2.3	5	0
17.0	18.0	80	6.3	9.1	3.4	0	0
12.0	17.0	84	9.4	11.9	6.3	0	0
15.0	15.0	83	8.5	11.7	6.4	0	0
15.0	20.0	84	6.4	8.9	4.2	0	0

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.9 MM
PRESSURE	550 KPA
ROTATION TIME	39 SECONDS
WETTED DIA.	35.6 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	22.0	83	6.5	8.6	3.6	0	0
22.0	22.0	80	4.9	6.6	2.2	8	0
16.5	16.5	81	8.7	12.2	5.7	0	0
24.4	24.4	79	4.0	5.6	2.0	12	2

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	PERROT ZE-30
NOZZLE SIZE(S)	4.5 MM
PRESSURE	400 KPA
ROTATION TIME	43 SECONDS
WETTED DIA.	31.7 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
22.0	22.0	67	3.2	5.4	1.4	40	23
19.0	22.0	69	3.7	5.6	1.4	30	19
18.0	24.0	72	3.5	5.6	1.4	23	11
17.0	18.0	74	5.0	9.1	2.0	9	2
12.0	17.0	79	7.5	11.1	4.1	0	0
15.0	15.0	77	6.8	11.1	4.8	0	0
15.0	20.0	79	5.1	8.9	2.2	3	0

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	RAINBIRD 40 EFC
NOZZLE SIZE(S)	3.6 MM
PRESSURE	400 KPA
ROTATION TIME	53 SECONDS
WETTED DIA.	28.4 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
20.0	20.8	67	2.9	5.2	0.8	43	15
20.0	15.6	78	3.8	5.5	1.9	16	5
18.0	18.0	73	3.7	5.4	1.8	24	13
14.0	28.0	60	3.1	5.5	0.0	37	18

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	4.0 MM
PRESSURE	400 KPA
ROTATION TIME	71 SECONDS
WETTED DIA.	29.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
18.5	18.5	74	3.6	5.7	1.7	18	9
18.5	22.0	70	3.0	4.6	1.4	37	18

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	4.0 MM
PRESSURE	500 KPA
ROTATION TIME	71 SECONDS
WETTED DIA.	29.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
18.5	18.5	73	3.8	5.5	1.7	19	10
18.5	22.0	72	3.2	5.0	1.5	34	16

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	4.0 MM
PRESSURE	550 KPA
ROTATION TIME	70 SECONDS
WETTED DIA.	29.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
18.5	18.5	75	4.0	5.7	1.9	19	7
18.5	22.0	73	3.4	5.4	1.5	29	11

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	4.8 MM
PRESSURE	400 KPA
ROTATION TIME	49 SECONDS
WETTED DIA.	33.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	16.5	77	6.4	11.2	4.4	0	0
16.5	22.0	80	4.8	7.7	2.0	7	0
18.5	18.5	77	5.2	9.3	2.6	4	0
18.5	22.0	75	4.3	5.8	2.1	13	0
22.0	22.0	70	3.6	5.8	2.0	22	0

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	4.8 MM
PRESSURE	500 KPA
ROTATION TIME	50 SECONDS
WETTED DIA.	34.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	16.5	78	7.2	11.5	4.6	0	0
16.5	22.0	80	5.4	8.0	2.2	3	0
18.5	18.5	76	5.8	9.1	3.0	0	0
18.5	22.0	77	4.9	6.8	2.2	7	0
22.0	22.0	74	4.1	6.2	2.2	16	0

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	4.8 MM
PRESSURE	550 KPA
ROTATION TIME	51 SECONDS
WETTED DIA.	34.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	16.5	79	7.4	11.3	5.1	0	0
16.5	22.0	82	5.5	8.0	2.5	2	0
18.5	18.5	77	5.9	9.1	3.2	0	0
18.5	22.0	78	5.0	7.0	2.2	7	0
22.0	22.0	76	4.2	6.2	2.2	16	0

TABLE A1 (Cont) Performance summaries for rectangular layouts

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	5.2 MM
PRESSURE	400 KPA
ROTATION TIME	43 SECONDS
WETTED DIA.	34.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	16.5	78	7.1	11.4	5.0	0	0
16.5	22.0	82	5.3	8.5	2.3	3	0
18.5	18.5	77	5.6	9.7	2.8	2	0
18.5	22.0	77	4.7	7.2	2.1	8	0
22.0	22.0	73	4.0	6.0	2.1	17	0

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	5.2 MM
PRESSURE	500 KPA
ROTATION TIME	44 SECONDS
WETTED DIA.	36.0 METRES
SETUP	RECTANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	16.5	81	8.1	12.1	6.0	0	0
16.5	22.0	83	6.1	9.2	3.3	0	0
18.5	18.5	79	6.5	10.3	3.7	0	0
18.5	22.0	79	5.4	7.9	2.5	3	0
22.0	22.0	77	4.6	6.6	2.4	11	0

TABLE A2 SPACING INDEX FOR RECTANGULAR LAYOUTS

Spacing	Pages
10.8 x 30.0	19
12.0 x 17.0	12*, 19, 20, 21
12.0 x 30.0	17
13.5 x 30.0	17
14.0 x 28.0	16, 22
15.0 x 15.0	12*, 19, 20, 21
15.0 x 20.0	12*, 19, 20, 21
15.0 x 22.0	16
15.0 x 30.0	17, 19
15.2 x 18.3	13, 14
15.6 x 20.0	13, 16, 22
16.5 x 16.5	16, 18, 20, 24*, 25, 26*
16.5 x 22.0	14, 18, 20, 24*, 25, 26*
17.0 x 18.0	12*, 19, 20, 21
18.0 x 18.0	16, 22
18.0 x 21.3	13, 16
18.0 x 22.0	17
18.0 x 24.0	12*, 19, 20, 21
18.0 x 30.0	19
18.3 x 18.3	13, 14
18.5 x 18.5	23*, 24*, 25, 26*
18.5 x 20.8	14
18.5 x 22.0	23*, 24*, 25, 26*
19.0 x 20.0	14
19.0 x 22.0	12*, 19, 20, 21
19.5 x 22.0	17*
19.5 x 25.6	19
20.0 x 20.8	14, 15*, 22
22.0 x 22.0	12*, 18, 19, 20*, 21, 24*, 25, 26*
24.4 x 24.4	20

Note: An asterisk by a page number indicates that more than one example of the listed spacing will be found on that page.

APPENDIX B

PERFORMANCE DATA FOR TRIANGULAR LAYOUTS

Two tables are presented in this Appendix. The first, Table B1, summarises the performance of the sprinklers tested at various spacings. These are listed by sprinkler type (alphabetically), nozzle size and nozzle pressure. The two right-hand columns in each list show the percentage of the area receiving less than or equal to (LEQ) 2.5 mm/hr and 2.0 mm/hr respectively. It is very important that anyone using this table fully understands the limitations of the data in it. These have been described in Section 5.2 (pg 9) of this report.

Table B2 (pg 42) is an index of the data by spacing. An asterisk by a page number in this index indicates that more than one example of the spacing will be found on that page.

TABLE B1 PERFORMANCE SUMMARIES FOR TRIANGULAR LAYOUTS

SPRINKLER TYPE	BAUER B70
NOZZLE SIZE(S)	4.5 MM
PRESSURE	400 KPA
ROTATION TIME	43 SECONDS
WETTED DIA.	32.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	22.0	80	4.2	7.3	2.0	9	3
22.0	22.0	80	3.1	6.8	2.0	28	10
16.5	16.5	80	5.5	7.5	3.4	0	0
18.3	24.4	77	3.4	6.9	2.0	24	0
18.3	18.3	75	4.5	7.1	2.2	10	0

SPRINKLER TYPE	BAUER B70
NOZZLE SIZE(S)	4.5 MM
PRESSURE	500 KPA
ROTATION TIME	38 SECONDS
WETTED DIA.	32.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	22.0	83	4.8	7.3	3.1	0	0
22.0	22.0	88	3.6	6.9	3.0	0	0
16.5	16.5	82	6.4	8.3	3.9	0	0
18.3	24.4	77	3.9	7.0	2.5	13	0
24.4	24.4	78	2.9	6.6	0.9	30	12
18.3	18.3	81	5.2	7.2	3.1	0	0

TABLE B1 (cont) Peformance summaries for triangular layouts

SPRINKLER TYPE D-SN 75
NOZZLE SIZE(S) 4.0 MM
PRESSURE 400 KPA
ROTATION TIME 80 SECONDS
WETTED DIA. 30.0 METRES
SETUP TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
18.0	18.0	68	3.3	9.1	1.5	35	18
16.5	16.5	72	4.0	9.1	1.8	19	4
16.5	22.0	72	3.0	9.1	1.6	37	12
20.0	15.6	68	3.5	9.1	1.5	32	18
22.0	15.0	69	3.3	9.1	1.6	35	16

TABLE B1 (Cont) Performance summaries for triangular layouts

SPRINKLER TYPE	D-SN 75
NOZZLE SIZE(S)	4.5 MM
PRESSURE	350 KPA
ROTATION TIME	59 SECONDS
WETTED DIA.	26.4 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
19.0	20.0	70	3.2	7.1	1.8	35	16
18.5	20.8	70	3.2	7.1	1.8	37	16

SPRINKLER TYPE	D-SN 75
NOZZLE SIZE(S)	4.5 MM
PRESSURE	400 KPA
ROTATION TIME	62 SECONDS
WETTED DIA.	26.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
20.0	20.8	74	3.4	6.8	1.4	28	13
16.5	16.5	59	5.2	10.4	1.9	24	14
16.5	22.0	67	3.9	7.6	1.8	24	8

TABLE B1 (Cont) Performance summaries for triangular layouts

SPRINKLER TYPE	D-SN 75
NOZZLE SIZE(S)	5.0 MM
PRESSURE	400 KPA
ROTATION TIME	58 SECONDS
WETTED DIA.	30.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	16.5	71	6.3	9.8	2.2	5	0
16.5	22.0	70	4.8	8.2	2.0	14	0
22.0	22.0	69	3.6	6.5	2.0	21	0
20.0	20.8	61	4.2	7.5	2.0	24	9

SPRINKLER TYPE	D-SN 75
NOZZLE SIZE(S)	5.0 MM
PRESSURE	550 KPA
ROTATION TIME	46 SECONDS
WETTED DIA.	32.8 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	22.0	77	6.3	9.0	3.0	0	0
20.0	20.8	71	5.5	2.4	8.2	10	0

TABLE B1 (Cont) Performance summaries for triangular layouts

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	3.4 MM
PRESSURE	400 KPA
ROTATION TIME	43 SECONDS
WETTED DIA.	26.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
16.5	16.5	77	3.2	7.6	2.0	22	0
20.0	15.6	77	2.8	7.6	1.9	37	8

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	3.9 MM
PRESSURE	400 KPA
ROTATION TIME	92 SECONDS
WETTED DIA.	31.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
16.5	22.0	71	3.2	5.6	1.0	29	9
16.5	16.5	72	4.2	6.1	1.1	15	9
18.3	18.3	64	3.4	6.1	1.0	32	26
18.0	18.0	65	3.5	6.1	1.0	28	23
18.0	21.3	64	3.0	5.7	1.0	36	29
14.0	28.0	76	2.9	5.1	1.2	33	19
22.0	15.0	66	3.5	6.0	1.0	25	18

TABLE B1 (Cont) Performance summaries for triangular layouts

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.4 MM
PRESSURE	400 KPA
ROTATION TIME	73 SECONDS
WETTED DIA.	31.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	22.0	72	4.0	7.0	1.7	20	11
22.0	22.0	65	3.0	5.1	1.6	44	29
16.5	16.5	73	5.4	7.5	1.7	9	4
18.3	24.4	69	3.3	5.1	1.6	36	22
18.3	18.3	66	4.4	7.6	1.6	25	22

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.4 MM
PRESSURE	450 KPA
ROTATION TIME	79 SECONDS
WETTED DIA.	30.4 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
23.8	19.0	63	3.3	6.3	1.6	38	27
22.0	28.0	71	2.4	4.9	0.2	60	27
22.0	18.0	62	3.6	6.8	1.5	37	29

TABLE B1 (Cont) Performance summaries for triangular layouts

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.4 MM
PRESSURE	500 KPA
ROTATION TIME	85 SECONDS
WETTED DIA.	30.8 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	22.0	73	3.8	6.1	1.6	24	11
16.5	16.5	72	5.1	7.3	1.6	15	10

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.9 MM
PRESSURE	400 KPA
ROTATION TIME	41 SECONDS
WETTED DIA.	33.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
22.0	22.0	75	3.5	5.2	1.9	21	6
19.0	22.0	73	4.1	5.8	1.8	15	6
18.0	24.0	77	3.9	5.8	2.0	19	5
17.0	18.0	75	5.5	7.8	2.1	6	0
12.0	17.0	82	8.3	10.9	5.1	0	0
15.0	15.0	87	7.5	9.4	5.2	0	0
15.0	20.0	80	5.7	7.6	3.3	0	0
16.5	16.5	78	6.2	8.3	2.9	0	0
18.3	24.4	76	3.8	5.7	1.9	18	4
18.3	18.3	72	5.1	7.5	1.9	12	3
16.5	22.0	78	4.7	6.5	2.1	8	0
24.4	24.4	85	2.8	4.5	1.9	46	7

TABLE B1 (Cont) Performance summaries for triangular layouts

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.9 MM
PRESSURE	500 KPA
ROTATION TIME	41 SECONDS
WETTED DIA.	34.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
22.0	22.0	80	4.0	5.6	2.2	10	0
19.0	22.0	78	4.6	6.3	2.2	10	0
18.0	24.0	79	4.5	6.5	2.3	5	0
17.0	18.0	77	6.3	8.4	2.6	0	0
12.0	17.0	84	9.4	11.9	6.5	0	0
15.0	15.0	87	8.5	1.3	5.9	0	0
15.0	20.0	83	6.4	8.1	3.9	0	0
16.5	22.0	81	5.3	6.8	2.6	0	0
16.5	16.5	79	7.0	9.0	3.7	0	0
18.3	24.4	79	4.3	6.5	2.3	5	0
24.4	24.4	87	3.2	4.7	2.2	16	0
18.3	18.3	75	5.7	8.0	2.2	5	0

TABLE B1 (Cont) Performance summaries for triangular layouts

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	4.9 MM
PRESSURE	550 KPA
ROTATION TIME	39 SECONDS
WETTED DIA.	35.6 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
16.5	22.0	82	6.5	8.3	3.6	0	0
22.0	22.0	77	4.9	6.6	2.2	8	0
16.5	16.5	83	8.7	10.9	4.9	0	0
24.4	24.4	86	4.0	5.6	2.2	8	0

SPRINKLER TYPE	NAAN 233/96
NOZZLE SIZE(S)	6.3 MM
PRESSURE	400 KPA
ROTATION TIME	25 SECONDS
WETTED DIA.	39.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
16.5	22.0	84	7.7	9.9	5.6	0	0
22.0	22.0	75	5.8	8.6	2.8	0	0
16.5	16.5	92	10.2	11.6	8.0	0	0
18.3	24.4	83	6.3	8.5	3.6	0	0
18.3	18.3	85	8.3	10.3	4.6	0	0
24.4	24.4	76	4.7	6.6	2.8	0	0

TABLE B1 (Cont) Performance summaries for triangular layouts

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	4.0 MM
PRESSURE	400 KPA
ROTATION TIME	71 SECONDS
WETTED DIA.	29.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
18.5	18.5	66	3.6	6.7	1.6	29	19
18.5	22.0	70	3.0	4.7	1.6	36	16

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	4.0 MM
PRESSURE	500 KPA
ROTATION TIME	71 SECONDS
WETTED DIA.	29.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
18.5	18.5	67	3.8	6.6	1.7	27	16
18.5	22.0	72	3.2	5.0	1.7	33	13

TABLE B1 (Cont) Performance summaries for triangular layouts

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	4.0 MM
PRESSURE	550 KPA
ROTATION TIME	70 SECONDS
WETTED DIA.	29.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
18.5	18.5	68	4.0	6.6	1.9	68	13
18.5	22.0	74	3.4	5.4	1.9	74	10

SPRINKLER TYPE	RAINSPRAY
NOZZLE SIZE(S)	4.8 MM
PRESSURE	400 KPA
ROTATION TIME	49 SECONDS
WETTED DIA.	33.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	16.5	79	6.4	8.7	2.9	0	0
16.5	22.0	77	4.8	7.7	2.1	8	0
18.5	18.5	69	5.2	8.5	2.1	10	0
18.5	22.0	71	4.3	7.2	2.0	15	0
22.0	22.0	69	3.6	5.7	2.0	22	0

TABLE B1 (Cont) Performance summaries for triangular layouts

SPRINKLER TYPE	RAINSPRAY
NOZZLE SIZE(S)	4.8 MM
PRESSURE	500 KPA
ROTATION TIME	50 SECONDS
WETTED DIA.	34.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	16.5	79	7.2	9.7	3.3	0	0
16.5	22.0	77	5.4	7.8	2.2	5	0
18.5	18.5	71	5.8	8.8	2.3	5	0
18.5	22.0	73	4.9	7.2	2.2	8	0
22.0	22.0	72	4.1	6.1	2.2	17	0

SPRINKLER TYPE	RAINSPRAY
NOZZLE SIZE(S)	4.8 MM
PRESSURE	550 KPA
ROTATION TIME	51 SECONDS
WETTED DIA.	34.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR MEAN	MAX	MIN	% AREA RECEIVING LEQ 2.5	2.0
16.5	16.5	80	7.4	9.9	4.5	0	0
16.5	22.0	79	5.5	7.6	2.4	3	0
18.5	18.5	72	5.9	8.6	2.4	4	0
18.5	22.0	74	5.0	7.1	2.3	9	0
22.0	22.0	72	4.2	6.1	2.2	14	0

TABLE B1 (Cont) Performance summaries for triangular layouts

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	5.2 MM
PRESSURE	400 KPA
ROTATION TIME	43 SECONDS
WETTED DIA.	34.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
16.5	16.5	82	7.1	9.2	3.8	0	0
16.5	22.0	78	5.3	7.9	2.3	4	0
18.5	18.5	71	5.6	8.7	2.2	6	0
18.5	22.0	72	4.7	7.5	2.1	10	0
22.0	22.0	69	4.0	6.4	2.1	21	0

SPRINKLER TYPE	RAINSPRAY 14F
NOZZLE SIZE(S)	5.2 MM
PRESSURE	500 KPA
ROTATION TIME	44 SECONDS
WETTED DIA.	36.0 METRES
SETUP	TRIANGULAR

SPACING METRES		CHRISTIANSENS UNIFORMITY COEFFICIENT %	INTENSITIES MM/HR			% AREA RECEIVING LEQ	
			MEAN	MAX	MIN	2.5	2.0
16.5	16.5	84	8.1	10.2	5.4	0	0
16.5	22.0	81	6.1	8.3	3.0	0	0
18.5	18.5	74	6.5	9.4	2.8	0	0
18.5	22.0	75	5.4	8.0	2.4	5	0
22.0	22.0	72	4.6	6.8	2.4	11	0

TABLE B2 SPACING INDEX FOR TRIANGULAR LAYOUTS

Spacing (m)	Pages
12.0 x 17.0	35, 26
14.0 x 28.0	33
15.0 x 15.0	35, 36
15.0 x 20.0	35, 36
15.0 x 22.0	30, 33
15.6 x 20.0	30, 33
16.5 x 16.5	29*, 30, 31, 32, 33*, 34, 35*, 36, 37*, 39, 40*, 41*
16.5 x 22.0	29*, 30, 31, 32*, 33, 34, 35*, 36, 37*, 39, 40*, 41*
17.0 x 18.0	35, 36
18.0 x 18.0	30, 33
18.0 x 21,3	33
18.0 x 22.0	34
18.0 x 24.0	35, 36
18.3 x 18.3	29*, 33, 34, 35, 36, 37
18.3 x 24.4	29*, 34, 35, 36, 37
18.5 x 18.5	38*, 39*, 40*, 41*
18.5 x 20.8	31
18.5 x 22.0	38*, 39*, 40*, 41*
19.0 x 20.0	31
19.0 x 22.0	35, 36
19.0 x 23.8	34
20.0 x 20.8	31, 32*
22.0 x 22.0	29*, 32, 34, 35, 36, 37*, 39, 40*, 41*
22.0 x 28.0	34
24.4, 24.4	29, 35, 36, 37*

Note: An asterisk by a page number indicates that more than one example of the listed spacing will be found on that page.

APPENDIX C

UNIFORMITY COEFFICIENTS

Uniformity of water application is of considerable importance in both irrigation and frost protection and several attempts have been made to develop numerical coefficients to describe this characteristic. One of the most widely used is the Christiansen's Uniformity Coefficient (Christiansen, 1942) and this has been used throughout this report.

This coefficient is defined as:-

$$Cu = 1 - \frac{\sum|\bar{x} - x|}{n\bar{x}} \quad 100\%$$

where

Cu = Christiansen's Uniformity Coefficient %,

x = the value of a particular observation of depth or intensity,

$\bar{x}$ = the mean of all the observations of depth or intensity,

n = the total number of observations, and

$\sum|\bar{x} - x|$ = the sum of the differences between $\bar{x}$ and each observation x, irrespective of whether the difference is positive of negative.

From this definition it can be seen that perfect uniformity will have a value of Cu of 100%. It should be noted however, that although the uniformity scale runs from 0 to 100% the coefficient does not have to fall very far before unacceptable performance occurs (from an irrigation or frost protection point of view). For example a system which contains dry areas in the overlapped area would clearly be unacceptable for most purposes and yet it may have a Christiansen's Coefficient as high as 65%.

Cu values of 80% or more would be considered very good.