VERY-LOW-PRESSURE SPRINKLE IRRIGATION

by

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January, 1977

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Abstract

Tests were conducted on the available sprinklers which can be operated at pressures of less than 4/3 atmosphere. Operating characteristics and design recommendations for the "best sprinkler" from each of the four types of very-low-pressure, VLP, sprinklers are presented. The four types include: spray heads, perforated pipe, reaction rotated sprinklers, and impact rotated sprinklers. The impact sprinkler appears to be superior for VLP operation and merits further developmental effort.

KEY WORDS: very-low-pressure sprinklers, sprinkle irrigation, low energy sprinkling

LIST OF TABLES

Table

1. Design data summary for the Mannesmann Model MR spray head sprinkler with 11/64-inch (4.5 mm) nozzle 13

2. Design data summary for Ames 0.75 or 1.0 inch (19 or 25 mm) per hour application rate perforated pipe 13

3. Design data summary for VLP operation of the Perma Rain Model "L" sprinkler with the recommended nozzle angle at 12 o'clock 16

4. Design data summary for VLP operation of the Rain Bird Model 20L-TNT impact sprinkler with an 11/64-inch nozzle 17

LIST OF FIGURES

Figure

1. The Mannesmann Model "MR" spray head sprinkler 5

2. Perforated pipe lateral in operation 6

3. Typical perforated pipe 7-hole pattern sequence every 30 inches to give 1.0 in/hr (or every 40 inches to give 0.75 in/hr application rate 7

4. The Perma Rain Model "L" reaction drive sprinkler 8

5. Effect of nozzle angle on the performance of the Perma Rain Model "L" reaction drive sprinkler with No. 6.5 nozzle at a pressure head of 0.82 atm or 27.7 feet 9

6. The Rain Bird Model 20L-TNT low pressure impact sprinkler 11

7. Average profile of water distribution from 5 test runs of a typical perforated pipe line at a pressure head of 1.36 atm or 46.2 feet operating in 0 to 3.3 mph (0 to 5.3 kph) winds 14

8. Uniformity of application from a Rain Bird 20L-TNT sprinkler operating at a pressure head of 1.02 atm or 34.6 feet (10.5 m) and spaced 20 feet along the row 18

TABLE OF CONTENTS

Introduction 1

Testing Program 3

Types of Very-Low-Pressure, VLP, Sprinklers 4

- Spray heads 4
- Perforated pipe 5
- Reaction drive 7
- Impact drive 10

Characteristics of Selected VLP Sprinklers 12

- Spray heads 12
- Perforated pipe 14
- Reaction drive 15
- Impact drive 15

Further Development 18

Summary 19

References 19

Appendix

- Fortran IV Program for Computing CU 20

VERY-LOW-PRESSURE SPRINKLE IRRIGATION[1/, 2/]

C. M. Burt, AMASAE and J. Keller, MASAE[3/]

Very-low-pressure, VLP, sprinkle irrigation is increasing in importance especially to agricultural developments in energy deficit areas. Using VLP is a viable method for conserving energy while maintaining the advantage of the sprinkle irrigation method. Sprinklers are adapted to fit many design requirements, and operating pressure is one of the factors that can be adjusted. Sprinkle irrigation systems are often classed according to the nozzle operating pressure. The classification system for revolving head sprinklers used by the Irrigation Association (Pair et al. 1975) is: low-pressure (1/3 to 2 atm), intermediate-pressure (2 to 4 atm), and high-pressure (above 4 atm). This study was conducted to explore the VLP (1/3 to 4/3 atm) portion of the low-pressure range.

Early in the development of sprinkle irrigation, most systems were operated with nozzle pressures in excess of 2 atm as pointed out by Christiansen (1942). He noted that with lower sprinkler pressures the distribution is usually less uniform, the application intensity (rate and drop impact) is greater and the sprinklers must be spaced closer together. He also noted that these disadvantages off-set the advantage

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2/ ASAE Paper #76-2517 for presentation at the 1976 Winter Meeting of the American Society of Agricultural Engineers, Palmer House, Chicago, Illinois. Dec. 14-17, 1976.

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of the power cost savings afforded by low-pressure operation. The relatively short wetted radius associated with low-pressure operation increases operating costs. With VLP sprinklers the diameter of the wetted circle is well under 40 feet (12 m); whereas, conventional intermediate-pressure impact sprinklers have over two times the wetted diameter covering 4 times the area. Thus, the farmer is faced with either buying more sprinklers, pipes, and fittings per unit area, or moving the sprinklers more frequently. Both of these alternatives are expensive.

In recent years, even in developed countries having low cost energy, there have been situations where VLP sprinkle systems were desirable. These include hose-pull and permanent under-tree orchard sprinklers, perforated pipes for orchards and row crops, systems operated with low gravity pressures (which would otherwise require pumping plants), and systems which utilize existing low pressure concrete pipe lines.

Throughout the world, there are many areas of land which are under-utilized due to a lack of good irrigation. Sprinkle irrigation has a distinct advantage over surface irrigation methods on many sites because of uneven topography, very sandy soil, or variable water intake rates throughout the fields. For example, during a recent study in Pakistan (Keller and Burt, 1975), it was noted that there were numerous patches of land scattered throughout the Indus basin which were poorly irrigated because they were too sandy, undulating, or were above the level of the gravity canal system.

In countries such as Pakistan, which depend heavily on imported fuel, a major factor preventing placing such lands under sprinkle irrigation is the high energy requirement associated with it. Trickle irrigation is sometimes suggested as a low-energy method of irrigation for areas which cannot be surface irrigated efficiently. Although the emitters may only require 1 to 2 atm pressure, pipeline friction loss, pressure regulating devices, and filtration system losses raise the necessary system inlet pressures to between 2 and 3 atm. Furthermore,

trickle irrigation only wets a small portion of an orchard area. This is considered an advantage in many developed countries, but it is not practical in countries where farms are small and where intercropping the young trees is a necessity.

Sprinkle equipment and system design standards in the United States have been developed in a cheap energy era. VLP sprinklers have only been used extensively in orchards. VLP sprinklers are seldom used in new system designs for field crops. This is because there are some physical problems associated with operating sprinklers at very low pressures, problems which have been overcome in the past by simply increasing the operating pressures. Until recently, using higher pressures and consequently more energy, seemed to be the most logical and economic approach. However, due to limited fuel supplies and increased fuel costs, study of VLP sprinklers is timely.

During the above mentioned study in Pakistan, it was concluded that an ideal system for irrigating all types of crops in the undulating sandy lands would be with VLP sprinklers operated from the ends of flexible hoses. (This is similar to the way many orchards and home gardens are irrigated in the United States except that intermediate-pressure sprinklers are used.) However, considerable difficulty was experienced in finding design and management information for VLP sprinklers. This led to interest in and the initiation of this study.

Testing Program

To begin the study at Utah State University and to determine the availability and performance of existing VLP sprinklers, letters were sent to over 50 irrigation equipment manufacturers throughout the world. Information and samples of sprinklers were requested which were practical to operate at pressures below 4/3 atm (20 psi). All sprinklers thus obtained were evaluated in an indoor test facility.

Tests were conducted with the sprinklers mounted on a 1/2-inch ips galvanized steel riser which was 30-inches (762 mm) tall. Sprinkler

base pressures and nozzle discharges were carefully measured. Catch data from a single radial row of containers placed on the floor and spaced 6 inches (152 mm) apart were taken after each sprinkler test had operated for a minimum of 30 minutes. The sprinklers were observed during operation and irregularities such as erratic turning and leakage of water at the bearings were noted.

The computer program presented in the Appendix was developed and used to evaluate the radial catch data. The program generates a grid pattern from a single radial line of catch data and superimposes the grid patterns to simulate various rectangular sprinkler spacings. The Coefficient of Uniformity , CU, (Christiansen, 1942) and application rate is then determined for each simulated spacing.

Types of Very-Low-Pressure, VLP, Sprinklers

The basic types of VLP sprinklers include non-rotating spray heads, perforated pipe lines, and rotating sprinklers. The rotating sprinklers are classed according to the means of rotation as reaction drive and impact drive.

Spray heads

The simplest VLP sprinkler is the stationary spray head type, which has no rotating mechanism. These are commonly used in the U.S. for residental sprinkling systems. Because they do not have any moving parts, these sprinklers can be durable, reliable and simple to operate and maintain. Disadvantages typical of these sprinklers include a small wetted diameter, narrow passages that are easily clogged and relatively high water application rates which are in excess of 1.0 inches (25 mm) per hour.

In spite of their poor performance in general, the Mannesmann Model MR (Figure 1)* gave surprisingly good results in distribution tests.

*Mention of specific product names does not imply preference or recommendation of a particular commercial product.

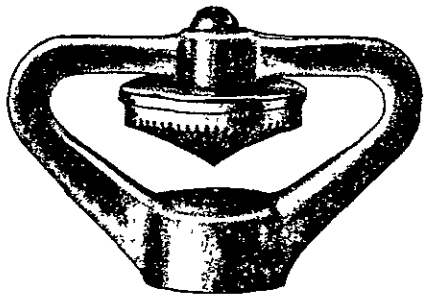

Figure 1. The Mannesmann Model "MR" spray head sprinkler.

This sprinkler has a slotted cone held above a large verticle nozzle with no narrow passages to clog. Because of the relatively good performance, freedom from clogging, and sturdiness of this sprinkler, it is widely used on small farms in West Germany. More effort may be warranted toward improving designs of this type of sprinkler, especially for use on center pivot systems where the moving sprinkler line reduces the importance of a very large wetted diameter.

Perforated pipe

Perforated pipe systems spray water from 1/16-inch (1.6 mm) diameter or smaller holes drilled along the top and sides of a pipe. The holes are sized and spaced so as to uniformly apply water between adjacent lines of perforated pipeline. The water issues from the holes and produces a rain-like application over a rectangular strip (Figure 2). Each hole emits a jet of water, which in rising and falling breaks up into small drops that are spread over the irrigated area by air turbulence.

The width covered, which ranges from 25 to 50 feet (7.6 to 15.2 m), increases as pressure increases. Such systems can operate effectively

Figure 2. Perforated pipe lateral in operation.

over the entire VLP range; however, they can only be used on soils having high infiltration capacities such as loamy sands and coarser textured soils, since the applications are typically 0.75 inches (19 mm) per hour or greater. Another disadvantage of perforated pipe is that the small holes are very sensitive to clogging. Even with adequate filtration of the water supply, clogging can be a problem due to debris picked up when moving the portable pipe sections, mineral deposits around the holes, and/or corrosion in metal pipes.

Most perforated pipe laterals have been made by drilling holes in portable aluminum sprinkler pipe. Figure 3 shows one of the standard hole sequences. The drilling can be done as a local enterprise or pre-drilled pipe can be obtained directly from the manufacturer; but in either case considerable care must be taken to de-burr the holes. No experience with perforated pipe laterals made of rigid PVC plastic was available, but PVC may be a suitable pipe material if the holes are drilled accurately and properly de-burred.

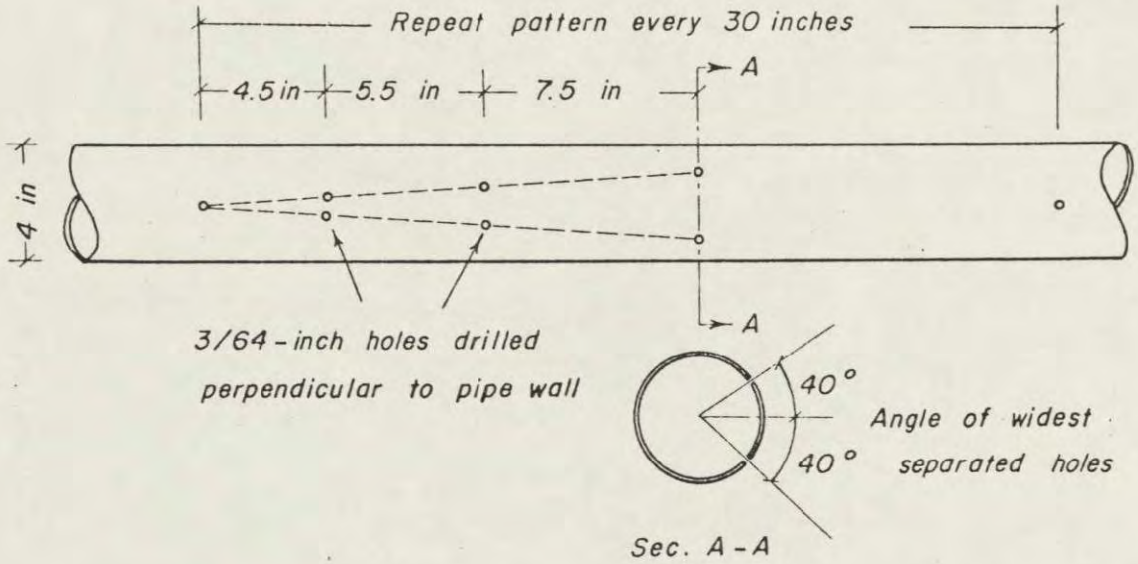

Figure 3. Typical perforated pipe 7-hole pattern sequence every 30 inches to give 1.0 in/hr (or every 40 inches to give 0.75 in/hr application rate. (1.0 inch = 25.4 mm).

Reaction drive

Rotating sprinklers are desirable for two reasons. First, since the entire water jet is concentrated in one or two directions rather than being dispersed 360 degrees (as with stationary spray heads), a much greater distance of throw is achieved with any given discharge rate. However, there must be a rotating mechanism to turn the sprinkler. The greater distance of throw leads to the second desirable feature which is that for any given discharge rate the application rate is decreased due to the increased area wetted.

Reaction drive sprinklers rely on the jet-thrust action of the water as it leaves the nozzle to provide the force necessary for rotation. Figure 4 shows a type of relatively slow turning reaction drive sprinkler. However, many reaction drive sprinklers turn very rapidly and, consequently, are called spinners.

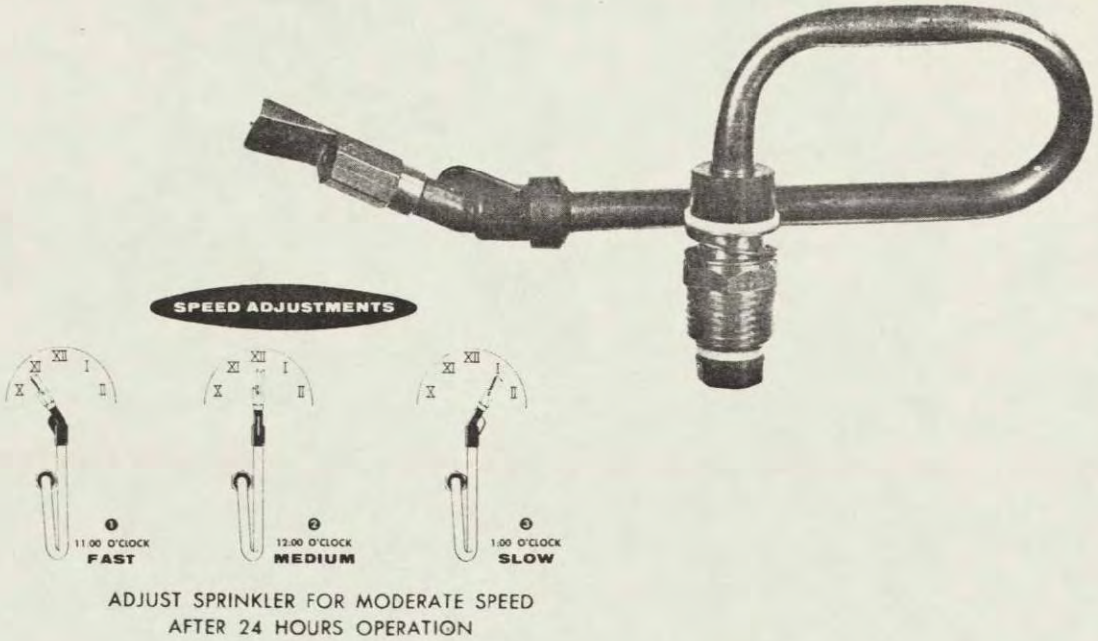

Figure 4. The Perma Rain Model "L" reaction drive sprinkler.

There are serious operational problems with reaction drive or spinner sprinklers at very low pressures. As the pressure is reduced, the turning force is also reduced because it is a function of both the discharge rate and the jet velocity. For all of the reaction sprinklers tested, rotation started erratically at pressure heads below 0.82 atm or 27.7 feet (8.44 m) even with a perfectly clean rotating collar. When the water is turned on, rotation is very slow at low pressures, gradually speeding up after a few minutes. A few grains of sand in the rotating collars can cause a sprinkler to stick regardless of the pressure.

Because connections around the collar must be loose to prevent jamming (a slight tension is generally provided by a collar spring), many of these sprinkers have about 5 per cent leakage around the collar at pressure heads lower than 0.82 atm or 27.7 feet (8.44 m). At higher pressures, however, this leakage decreases to less than 1 per cent.

Reaction sprinklers generally have adjustable nozzles or arm angles used to aid the irrigator in adjusting the speed of rotation or the

angle of trajectory. Unfortunately, the water pattern is greatly changed by minor adjustments in nozzle angle as depicted by the application rate data along a radial leg shown in Figure 5. Therefore, the optimum angle adjustment for good distribution should be determined, pre-set and locked in position.

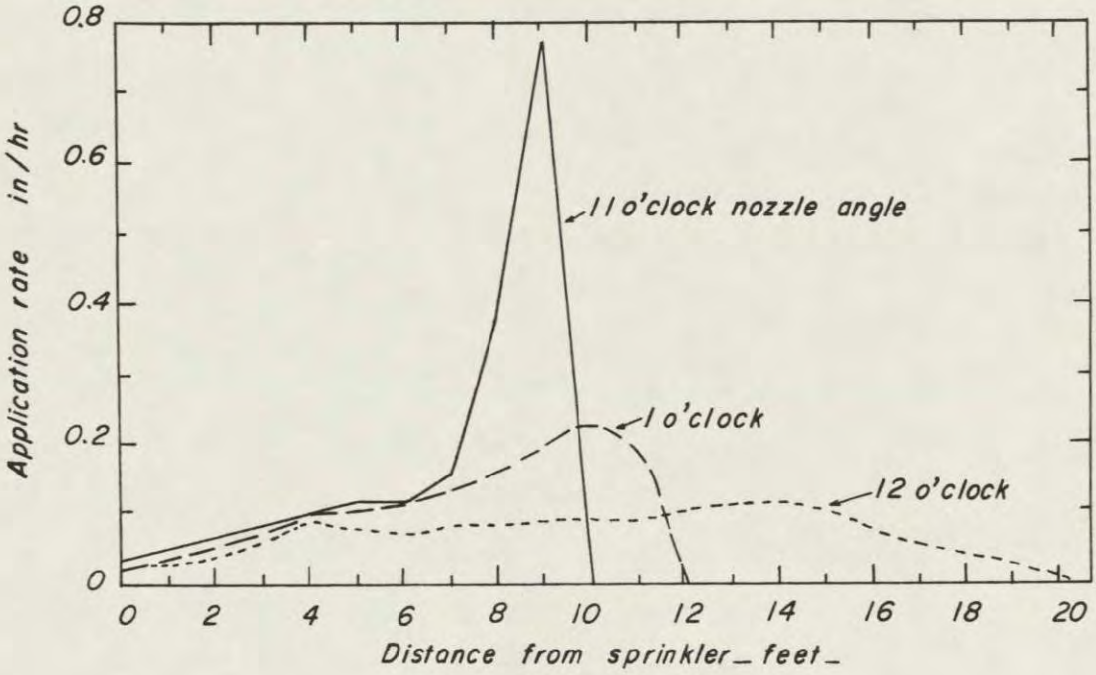

Figure 5. Effect of nozzle angle on the performance of the Perma Rain Model "L" reaction drive sprinkler with No. 6.5 nozzle at a pressure head of 0.82 atm or 27.7 feet. (1.0 inch = 25.4 mm, 1.0 feet = 0.305 m).

Since the rotating collars must be relatively loose to prevent jamming, the sprinklers tend to spin too fast which reduces the range of throw. For example, the relatively slow turning Perma Rain Model "L" sprinkler with a No. 5.5 nozzle set at the 12 o-clock position and operating at a pressure head of 0.82 atm or 27.7 feet (8.44 m) has a wetted radius of 19 feet (5.79 m) when held stationary, but only a 15.5 foot (4.72 m) wetted radius when rotating normally. Thus there would be a 50 percent increase in wetted area if the sprinkler could be made to rotate much slower.

One way to increase the moment (force x distance) of a reaction sprinkler and yet decrease the speed of rotation is to increase the length of the arms. By doubling the arm length, the moment is doubled, but the angular acceleration is cut in half.

As part of the study, several models of reaction sprinklers were tested. These included the Perma Rain Models "L" and "C", Buckner cooling sprinklers, the Roberts Model 450, and the Browning B-21 sprinkler. Of these sprinklers, only the Perma Model "L" operated satisfactorily and gave a reasonably good water distribution pattern at pressure heads less than 1.36 atm or 46.2 feet (14.08 m).

Both the Buckner cooling sprinklers and the Roberts sprinkler have two short arms with simple nozzles. Rather than using machined nozzles at the end of the arms, holes or slits are cut into the sides of the arms. Even after carefully adjusting the angles and operating pressures, these sprinklers gave very distinct "doughnut" type wetting patterns. If the two arms were adjusted at different angles, there were two "doughnut" rings around the sprinkler rather than one.

The tests showed that a more elaborate nozzle design other than a simple hole at the end of the arm is necessary for good distribution uniformity. However, for under-tree irrigation where most reaction sprinklers are commonly used, distribution uniformity may be less important than it would be for field crops.

Impact drive

Impact sprinklers are driven by the sharp impact of the driving arm which is activated by the water jet. These sharp impacts keep the sprinkler rotating even under adverse conditions. The only impact sprinkler designed specifically for VLP operation is the Rain Bird Model 20L-TNT shown in Figure 6. This impact sprinkler is basically a rugged intermediate-pressure brass sprinkler with some essential modifications for operation at very low pressure. They include a low-tension stainless steel arm and bearing springs and a special fixed-pin brass nozzle.

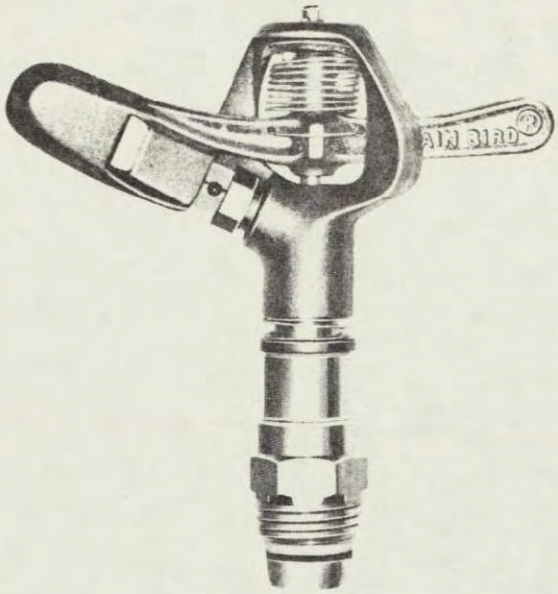

Figure 6. The Rain Bird Model 20L-TNT low pressure impact sprinkler.

The fixed-pin nozzle is used to provide better stream breakup by disrupting the flow immediately after it leaves the orifice. This improved breakup occurs at the expense of a reduced wetted diamter. For example, with a 7/32 inch nozzle operating at a pressure head of 0.82 atm or 27.7 feet (8.44 m) without a pin, the wetted radius is approximately 32.5 feet (9.91 m). With the fixed-pin to break up the stream the wetted radius is reduced to 27.0 feet (8.23 m), which results in a 21 percent decrease in wetted area. However, without the pin for breakup, most of the water lands in a narrow band near the edge of the wetted circle producing what is typically referred to as a "doughnut" pattern.

The rotating mechanism is powered by the water thrust on the impact driving arm, consequently rotation becomes erratic when the pressure is too low. However, the sprinkler still operated fairly well at a pressure head of only 0.32 atm or 10.8 feet (3.3 m).

Characteristics of Selected VLP Sprinklers

The unavoidable pressure differences at different sprinklers within the same field is a source of poor application uniformity common to all VLP systems since pressure differences are a larger proportion of the total pressures. For example, the discharge rate of a sprinkler will increase by 22 percent when the pressure head is increased 50 percent from 23.10 to 34.65 feet (7.04 to 10.56 m). The same absolute pressure head increase of 11.55 feet (3.52 m), however, would only increase the discharge rate by 5 percent if the operating head was increased from 115.5 to 127.05 feet (35.20 m to 38.72 m).

Another general problem associated with lower pressures is the combination of high water application rates and large droplets, both of which cause destruction of soil structure and an eventual descrease in water intake rates as pointed out by Pair et al (1975). The "doughnut" pattern mentioned above plus a relatively short wetted radius can cause the high application rates. At higher pressures, turbulence increases in the nozzle and water leaves as a more dispersed jet. The wetted radius is greater and the area receives a more uniform application of water. In addition, water droplets are smaller.

The overall operation of each sprinkler was judged in terms of suitability for VLP sprinkle irrigation of field crops. The best performing sprinkler-model-nozzle combinations were selected for each type. The criteria for the selection, by judgment, was based on ruggedness, proneness to leak, maximum spacing, drop size, and application rate. Maximum spacing for each sprinkler was assumed to be the widest spacing at which each sprinkler-nozzle-pressure would produce a Christiansen's Uniformity Coefficient greater than 80 percent.

Spray heads

The spray head sprinklers required close spacings and produced high application rates. The Manesmann model "MR" with an 11/64-inch (4.5 mm) nozzle was the best performing spray head sprinkler. Table 1 gives the

Table 1. Design data summary for the Mannesmann Model MR spray head sprinkler with 11/64-inch (4.5 mm) nozzle.

Sprinkler Base Pressure Head (ft)	Discharge (gpm)	Minimum Recommended Rectangular Spacing* (ft x ft)	Application Rate (in/hr)
41.6	2.83	15 x 15	1.21
34.6	2.74	15 x 15	1.10
27.7	2.45	12 x 15	1.24
20.8	2.12	12 x 12	1.34

*For Coefficients of Uniformity greater than 80% in low winds.
(1.0 ft = 0.0295 atm = 0.305 m, 1.0 gpm = 0.063 lps, 1.0 in = 25.4 mm).

Table 2. Design data summary for Ames 0.75 or 1.0 inch (19 or 25 mm) per hour application rate perforated pipe.

Pipe Pressure Head (ft)	Discharge per 100 ft of Pipe 0.75 iph (gpm)	Discharge per 100 ft of Pipe 1.0 iph (gpm)	Maximum Recommended Spacing (ft)
41.6	42	54	43
34.6	37	49	38
27.7	34	44	35
20.8	29	38	30
13.9	23	32	25
9.2	20	28	20

(1.0 ft = 0.0295 atm = 0.305 m, 1.0 gpm = 0.063 lps, 1.0 in = 25.4 mm).

design summary data for this sprinkler. This sprinkler was selected because it is rugged, not prone to clogging, and simple. Information as to sources of supply and prices can be obtained from: Manesmann-Rohrbau, Abetilung Lantechnik, 4 Dusseldorf, Theodorstrasse 90, West Germany.

Perforated pipe

Perforated pipe was not tested during this study and data presented below was taken from the Ames Irrigation Handbook (Keller et al. 1967). This data was confirmed in Italy in 1957, by Dr. Armando Chieffo.

Perforated pipe irrigates in rectangular strips and the spray pattern is not greatly distorted by winds up to 5 mph (8 kph). The application rate is rather uniform across the wetted strip as depicted in Figure 7 and an overlap of only 3 to 5 feet (0.91 to 1.52 m) is needed to assure good uniformity and coverage.

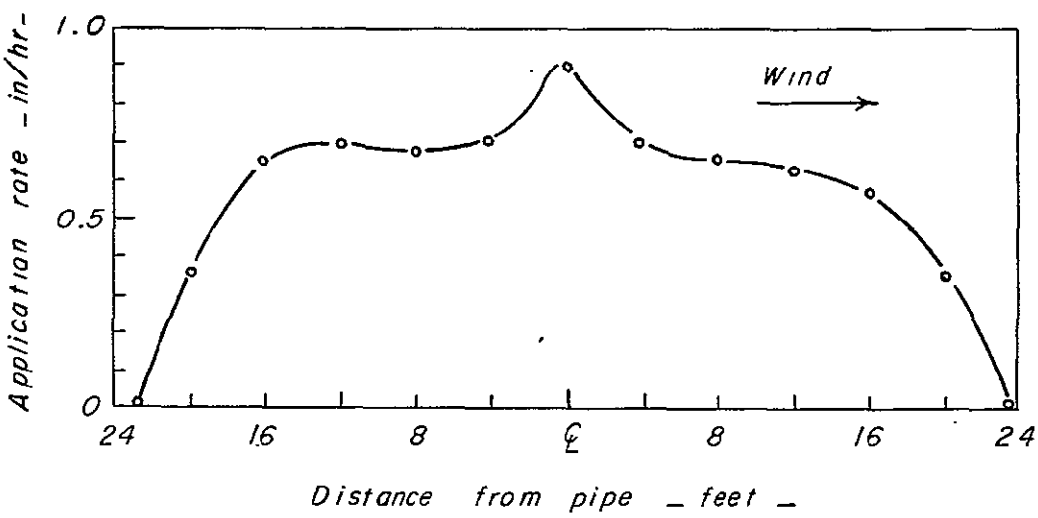

Figure 7. Average profile of water distribution from 5 test runs of a typical perforated pipe line at a pressure head of 1.36 atm or 46.2 feet operating in o to 3.3 mph (0 to 5.3 kph) winds. (1.0 feet = 0.305 m, 1.0 inch - 25.4 mm).

Table 2 gives the design data summary for 0.75 and 1.0 inch per hour perforated pipe as shown in Figure 3. Perforated pipe can be manufactured locally or obtained commercially. Information as to sources of supply and prices can be obtained from: Lockwood (Ames) Corporation, U.S. Highway 92 East, Gearing, Nebraska 69341, USA.

Reaction drive

The Perma Rain Model "L" sprinkler with the nozzle angle set at 12 o'clock was the best performing reaction drive sprinkler tested. This sprinkler was selected because it produced low application rates with small drops which makes it applicable for use on low infiltration rate soils. It also can be widely spaced. The major disadvantages of this sprinkler are that it can be knocked out of adjustment easily, and it can jam causing it to turn erratically or stop rotating.

Table 3 gives the design summary data for this sprinkler. Information as to the sources of supply and prices can be obtained from: Perma Rain Irrigation, Inc., P. O. Box 880, Lindsay, California 93247, USA.

Impact drive

The Rain Bird Model 20L-TNT was the only impact sprinkler available which was specifically designed for VLP operation. As with perforated pipe, this sprinkler can be operated with pressure heads as low as 0.32 atm or 10.8 feet (3.3 m) and can be spaced up to 40 feet (12.2 m) when the pressure head is in the range of 1.02 atm or 34.6 feet (10.5 m). However, the impact sprinkler has three very important advantages over perforated pipe. It has a single large orifice which is not subject to clogging, it can be operated in higher wind, and most important, it produces considerably lower application rates.

Table 4 gives the design summary data for this sprinkler with an 11/64-inch nozzle . The 11/64-inch nozzle was chosen because it gave the best uniformity of all the nozzles tested (Figure 8) with the lowest discharge and application rate. Information as to sources of

Table 3. Design data summary for VLP operation of the Perma Rain Model "L" sprinkler with the recommended nozzle angle at 12 o'clock.

Sprinkler Base Pressure (ft)	Nozzle No.	Discharge (gpm)	*Maximum Recommended Rectangular Spacing (ft x ft)	Application Rate in/hr
41.6	2.5	.24	10 x 20	0.12
	4.0	.32	15 x 25	0.08
	5.5	.68	15 x 25	0.17
	6.5	.96	15 x 30	0.21
34.6	2.5	.22	10 x 15	0.14
	4.0	.29	10 x 15	0.19
	5.5	.62	10 x 25	0.24
	6.5	.86	15 x 30	0.18
27.7	2.5	.20	10 x 15	0.13
	4.0	.27	10 x 15	0.17
	5.5	.56	10 x 25	0.22
	6.5	.77	15 x 30	0.16
20.8**	4.0	.23	10 x 10	0.22
	5.5	.48	10 x 25	0.18

*For Coefficients of Uniformity greater than 80% in low winds.
**Operation at pressures less than 20.8 feet are not recommended because of rotation and leakage problems.

(1.0 ft = 0.0295 atm = 0.305 m, 1.0 gpm = 0.063 lps, 1.0 in = 25.4 mm)

Table 4. Design data summary for VLP operation of the Rain Bird Model 20L-TNT impact sprinkler with an 11/64-inch nozzle.

Sprinkler Base Pressure (ft)	Discharge (gpm)	*Maximum Recommended Rectangular Spacing (ft x ft)	Application Rate in/hr
41.6	3.41	20 x 40	0.41
34.6	3.11	20 x 40	0.37
27.7	2.79	20 x 40	0.34
18.5	2.27	20 x 25 15 x 40	0.44 0.36
14.5	2.01	15 x 35	0.37
10.8	1.74	15 x 15 10 x 30	0.74 0.56

*For Coefficients of Uniformity greater than 80% in low winds.

(1.0 ft = 0.0295 atm = 0.305 m, 1.0 gpm = 0.063 lps, 1.0 in = 25.4 mm)

supply and prices can be obtained from: Rain Bird Sprinkler Mfg. Corp., 7045 N. Grand Avenue, Glendora, California 91740, USA..

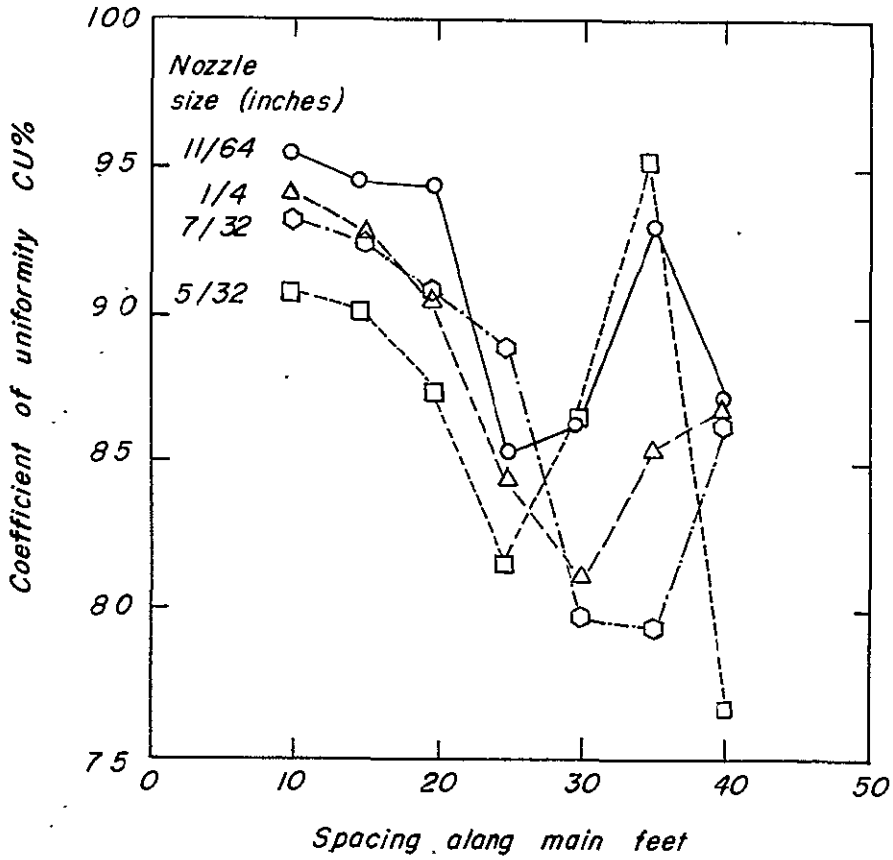

Figure 8. Uniformity of application from a Rain Bird 20L-TNT sprinkler operating at a pressure head of 1.02 atm or 34.6 feet (10.5 m) and spaced 20 feet along the row.

Further Development

The tests indicate that further development work on VLP sprinklers should concentrate on impact sprinklers. This is because of: (a) their potential for a larger wetted diameter and their superior resistance to jamming when compared to reaction sprinklers; (b) their potential for a larger wetted diameter and lower application rate when compared to spray

heads; and (c) their lower sensitivity to clogging and (d) their lower application rates when compared to perforated pipe.

Developmental research is now underway at Utah State University in an effort to improve the performance of VLP impact sprinklers. This research is in the areas of rotation dynamics and nozzle design. A complete understanding of the factors involved in the rotation mechanism may enable designers to build impact sprinklers for VLP operation which will perform better and not require the relatively high discharge quantities presently necessary for rotating the sprinkler. Hopefully, nozzles can be designed which will allow some of the water to leave the nozzle as an undisturbed jet, achieving maximum distance of trajectory, and yet have enough of the stream broken up to provide a good distribution pattern close to the sprinkler.

Summary

Tests were conducted on the available sprinklers which can be operated at pressures of less than 4/3 atmosphere. Operating characteristics and design recommendations for the "best sprinkler" from each of the four types of very-low-pressure, VLP, sprinklers are presented. The four types include: spray heads, perforated pipe, reaction rotated sprinklers, and impact rotated sprinklers. The impact sprinkler appears to be superior for VLP operation and merits further developmental effort.

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APPENDIX

Fortran IV Program for Computing CU

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      DIMENSION ACTD(40,40),ACTQ(40),HDG1(12),EST3(100,100)
      DIMENSION HDG2(12),LENLL(60),LENWW(60),EST1(100,100),EST2(100,100)
      INTEGER LENGTH, WIDTH
C
C     ************************************************************** *
C
C     THIS PROGRAM USES THE DATA FROM ONE RADIAL LEG, WITH NO WIND, AND
C     CALCULATES THE COEFFICIENT OF UNIFORMITY AT DIFFERENT SPACINGS
C
C    THIS PROGRAM WILL HANDLE SPACINGS WHICH ARE SO WIDE THAT THE WATER
C     FROM ADJACENT SPRINKLERS WILL NOT MEET, AND NARROW SPACINGS WHICH
C     CAN HAVE OVERLAP FROM UP TO A DISTANCE OF 4 SPRINKLERS AWAY
C
C     CARD 1   CONTAINS THE NUMBER OF SPACING COMB. THAT WILL BE TRIED
C     CARD 2 PLUS MANY OTHERS, DEPENDING ON THE NUMBER OF COMBINATIONS,
C          CONTAINS ONE COMBINATION, IN FT X FT.  FOR EXAMPLE, IT WILL
C         HAVE, IN 2I5 FORMAT, THE NUMBERS 20   20.  THIS MEANS A 20
C         BY 20 FT SPACING.  THERE IS ONE CARD FOR EACH SPACING COMB.
C     NOW STARTS THE INPUT FOR THE INDIVIDUAL SPRINKLER DATA.  ALL OF
C      THE SPRINKLERS WILL HAVE THE SAME MOVE COMBINATIONS TESTED.
C     FOR THE SPRINKLER INFORMATION, THE FIRST DATA CARD IMMEDIATELY
C     FOLLOWS THE LAST COMBINATION.  IT WILL BE CALLED CARD 1A
C     CARD1A  CONTAINS THE SPRINKLER MODEL NAME  (FORMAT 12A6)
C     CARD 2A CONTAINS THE NOZZLE, AND PRESSURE INFORMATION FORM(12A6)
C     CARD 3A  CONTAINS THE GPM (FORMAT F5.2)
C     CARD 4A CONTAINS DISTANCE OF MAX SPRINK. THROW (FORMATI2)
C     CARD 5A CONTAINSTHE FIRST OF THE CATCH CAN DATA, STARTING WITH
C       THE CATCH AT THE SPRINKLER ITSELF.  THERE MAY BE ABOUT 3 CARDS
C       WITH THE CATCH CAN DATA ON IT, IN FORMAT (8F10.1)
C     THE NUMBER OF CATCH CAN POINTS EQUALS THE MAXIMUM THROW DISTANCE
C        PLUS 1
C     THIS PROGRAM HAS BEEN WRITTEN FOR CANS SPACED 1 FOOT APART
C     AFTER THE LAST CATCH CAN DATA CARD, THE SPRINKLER INFORMATION FOR
C     THE NEXT SPRINKLER IS PUT IN, STARTING WITH THE SPRINKLER NAME.
C
C    ************************************************************** ****
C
      READ(5,6) NQ

      READ(5,3I)(LENLL(I),LENWW(I),I = 1,NQ)
C     NQ IS THE NUMBER OF SPACING COMBINATIONS
    1 READ(5,5,END=99) HDG1,HDG2
      READ(5,7) GPM
      READ(5,6) NUM1
C     NUM1 IS THE MAS DISTANCE OF THROW IN FT, AS INTEGER
      NUM = NUM1+ 1
      READ(5,10)(ACTQ(I),I=1,NUM)
      WRITE(6,20) HDG1

      WRITE(6,38)  HDG2
      WRITE(6,37)
      WRITE(6,45)(ACTQ(I),I=1,NUM)
      WRITE(6,11) GPM
      WRITE(6,12)
C     TO CALCULATE DISTANCE TO EACH POINT ON A 25 BY 25 FOOT GRID, W/
C     SPACINGS OF 1.0 FT
       DO 500 I = 1,NUM
      DO 500 J = 1,NUM
```

```
  500 ACTD(I,J)=(((I-1)**2. +(J-1)**2.)**.5)
C     ACTD IS THE ACTUAL DISTANCE IN FT FROM SPRINKLER TO GRID POINT
C       TO ESTIMATE THE CATCH A CERTAIN DISTANCE AWAY, FIRST READ IN
C     THE RADIAL LEG DATA (ALREADY DONE).  IF THE MAX LEG LENGTH IS
C      25 FT AND SPACINGS OF THE CANS ARE 1 FT, THERE ARE 25 POINTS
C     ACTQ IS ACTUAL RADIAL LEG CATCH PER CAN IN MILLILITERS
C     TO FIND THE PROPER QUANTITY IN THE SQUARE GRID CANS, EACH CAN
C     IS MATCHED WITH QUAN FROM THE SAME DISTANCE AWAY ON THE LEG.
C      EST3 IS THE CALCULATED CATCH, FOR THE GRID POINTS
      DO 600 I = 1,NUM
      DO 600 J = 1,NUM
      S = 0.
      DO 190 K = 1,NUM
      N = K+1
      SA = S-ACTD(I,J)
      IF(SA.GE.-1.)GO TO 210
      S = S + 1.
  190 CONTINUE
  210 EST3(I,J)= ACTQ(K) - (SA*(ACTQ(N)-ACTQ(K)))
  600 CONTINUE
C     FIGURE THE OVERLAY DUE TO SPACING ALONG THE PIPE
      IQB = 0
  690 IQB = IQB + 1
      IF(IQB.GT.NQ) GO TO 1
      LENL = LENLL(IQB)
      LENW = LENWW(IQB)
      DO 212 I = 1,NUM
      DO 212 J = 1,NUM
  212 EST1(I,J) = EST3(I,J)
C
C     LENL IS THE SPACING ALONG THE LINE IN FEET, OF THE SPRINKLERS
C      LENW IS THE SPACING BETWEEN MOVES (LATERAL) IN FEET
C      DUE TO THE OVERLAP BY THE SPRINKLER ON THE SAME PIPE
      NUB = NUM +1
      N1 = LENL + 1
      NN = N1
      N2 = LENL + 1
      N3 = 2*LENL+1
      N4 = 2*LENL+1
      N5 = 3*LENL + 1
      N6 = 3*LENL + 1
      N7 = 4*LENL + 1
C    THIS EJECTS COMBINATIONS WITH MORE THAN 4 OVERLAPS
      OX = NUM-4*LENL
      IF(OX.GT.0) GO TO 98
C   COVERS FROM NUM=4*LENL TO  NUM=3*LENL+1
      OX1 = (3*LENL+1)-NUM
      IF(OX1.GT.0) GO TO 60
      DO 50 I = NUB,N7
      DO 50 J = 1,NUM
   50 EST1(I,J) = 0.0
      DO 53 I = 1,NN
      DO 52 J = 1,NUM
   52 EST2(I,J)=EST1(I,J)+EST1(N1,J)+EST1(N2,J)+EST1(N3,J)+EST1(N4,J)+
     1EST1(N5,J)+EST1(N6,J)+EST1(N7,J)
      N1 = N1 + 1
      N2 = N2-1
      N3 = N3+1
      N4 = N4-1
      N5 = N5+1
      N6 = N6-1
```

```
   53 N7 = N7-1
      GO TO 90
C    COVERS FROM NUM=3*NUM  TO  NUM=2*LENL+1
   60 OX2=2*LENL+1-NUM
      IF(OX2.GT.0) GO TO 70
      DO 64 I = NU3,N5
      DO64 J=1,NUM
   64 EST1(I,J)=0.0
      DO 63 I = 1,NN
      DO 62 J=1,NUM
   62 EST2(I,J)=EST1(I,J)+EST1(N1,J)+EST1(N2,J)+EST1(N3,J)+EST1(N4,J)+
     1EST1(N5,J)
      N1 = N1 + 1
      N2 = N2-1
      N3 = N3+1
      N4 = N4-1
   63 N5 = N5-1
      GO TO 90
C    COVERS FROM NUM=2*LENL TO  NUM=LENL+1
   70 OX3=LENL+1-NUM
      IF(OX3.GT.0) GO TO 80
      DO 74 I = NU3,N3
      DO 74 J = 1,NUM
   74 EST1(I,J) =0.0
      DO 73 I = 1,NN
      DO 72 J = 1,NUM
   72 EST2(I,J)=EST1(I,J)+EST1(N1,J)+EST1(N2,J)+EST1(N3,J)
      N1 = N1 + 1
      N2 = N2-1
   73 N3 = N3-1
      GO TO 90
   80 CONTINUE
C    COVERS SPACING W/O OVERLAP FROM MORE THAN THE NEXT SPRINKLER
      DO 86 I = NU3,NN
      DO 86 J = 1,NUM
   86 EST1(I,J) = 0.0
      DO 93 I = 1,NN
      DO 92 J = 1,NUM
   92 EST2(I,J) = EST1(I,J) + EST1(N1,J)
   93 N1 = N1-1
C
C    TO FIGURE OVERLAP DUE TO SPACING BETWEEN ROWS, DO A SIMILAR
C      PROCESS, BUT ALLOWING I TO VARY FROM 1 TO LENL+1
C
   90 N1=LENW+1
      NW = N1
      N2 = LENW + 1
      N3 = 2*LENW+1
      N4 = 2*LENW+1
      N5 = 3*LENW+1
      N6 = 3*LENW+1
      N7 = 4*LENW+1
      DO 91 I = 1,LENL
      DO 91 J = 1,NUM
   91 EST1(I,J) = EST2(I,J)
C    WHEN READING IN LENLL AND LENW, LENLL IS LESS THAN LENW.
C      THEREFORE, COMBINATIONS WITH MORE THAN 4 OVERLAPS HAVE ALREADY
C       OBEEN DELETED
C    COVERS FROM NUM=4*LENW  TO  NUM=3*LENW+1
      OW1 = 3*LENW+1-NUM
      IF(OW1.GT.0) GO TO 310
```

```
      DO 300 J = NJB,N7
      DO 300 I = 1,LENL
  300 EST1(I,J) = 0.0
      DO 303 J = 1,NW
      DO 302 I = 1,LENL
  302 EST2(I,J)=EST1(I,J)+EST1(I,N1)+EST1(I,N2)+EST1(I,N3)+EST1(I,N4)
     1+EST1(I,N5)+EST1(I,N6)+EST1(I,N7)
      N1 = N1 + 1
      N2 = N2-1
      N3 = N3+1
      N4 = N4-1
      N5 = N5+1
      N6 = N6-1
  303 N7 = N7-1
      GO TO 700
C   COVERS FROM NUM=3*LENW  TO  2*LENW+1
  310 OW2 = 2*LENW+1-NUM
      IF(OW2.GT.0) GO TO 320
      DO 314 J = NUB,N5
      DO 314 I = 1,LENL
  314 EST1(I,J) = 0.0
      DO 313 J = 1,NW
      DO 312 I = 1,LENL
  312 EST2(I,J)=EST1(I,J)+EST1(I,N1)+EST1(I,N2)+EST1(I,N3)+EST1(I,N4)
     1+EST1(I,N5)
      N1 = N1 + 1
      N2 = N2-1
      N3 = N3+1
      N4 = N4-1
  313 N5=N5-1
      GO TO 700
C   COVERS FROM NUM=2*LENW  TO NUM=LENW+1
  320 OW3 = LENW+1-NUM
      IF(OW3.GT.0) GO TO 330
      DO 324 J = NJB,N3
      DO 324 I = 1,LENL
  324 EST1(I,J) = 0.0
      DO 323 J = 1,NW
      DO 322 I = 1,LENL
  322 EST2(I,J)=EST1(I,J)+EST1(I,N1)+EST1(I,N2)+EST1(I,N3)
      N1 = N1 +1
      N2 = N2-1
  323 N3 = N3-1
      GO TO 700
  330 CONTINUE
      DO 336 J = NJB,NW
      DO 336I = 1,LENL
  336 EST1(I,J) =0.0
      DO 339 J = 1,NW
      DO 338 I = 1,LENL
  338 EST2(I,J)=EST1(I,J)+EST1(I,N1)
  339 N1=N1-1
  700 CONTINUE
      DO 701 I = 1,LENL
      DO 701 J = 1,LENW
  701 EST1(I,J) = EST2(I,J)
      SU = 0.
      SUM = 0.
      DO 760 I = 1,LENL
      DO 760 J = 1,LENW
      SUM = SUM + EST1(I,J)
```

```
760 SU = SU + 1.
    SMEAN = SUM/SU
    SDEV = 0.
    DO 765 I = 1,LENL
    DO 765 J = 1,LENW
765 SDEV = SDEV + ABS(EST1(I,J)-SMEAN)
    CU = 100. * (1. - (SDEV/SUM))
    APPL = GPM*96.3/(LENL*LENW)
    WRITE(6,13) LENL, LENW, CU, APPL
    GO TO 690
 98 CU = 100000000.
    APPL = 0.0
    WRITE(6,13) LENL, LENW, CU, APPL
    GO TO 690
999 CONTINUE
    GO TO 1
  5 FORMAT(12A6)
  6 FORMAT(I2)
  7 FORMAT(F5.3)
 10 FORMAT(8F10.1)
 11 FORMAT(1X,'GPM=',F5.3)
 12 FORMAT(//,1X,'SPACING(FT)    RECT. CU    IN/HR')
 13 FORMAT(2X, I2, ' X ',I2,8X,F5.1,6X,F4.2)
 20 FORMAT('1',1X,12A6)
 31 FORMAT(2I5)
 37 FORMAT(1X,'ACTUAL CAN CATCH DATA =')
 38 FORMAT(12A6)
 45 FORMAT(10 F10.2)
 99 STOP
    END
```

PROJECT NUMBER:

PROCESS:	ACTION:	DATES:	INITIALS:
CATALOGUE	1656NS		
ABSTRACT			
FICHE	RANDD		

COMMENTS:

DS/DIU