THE EFFECT OF SLOPE AND WIND ON WATER DISTRIBUTION PATTERNS OF MODERATE PRESSURE ROTARY IRRIGATION SPRINKLERS

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

S. M. Siddiqi Quadri

1957

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By

S. M. Siddiqi Quadri

AN ABSTRACT

Submitted to the College of Agriculture of Michigan State
University of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Agricultural Engineering

1957

Approved by E H Kidder

During the 1930's, portable sprinkler irrigation systems were developed, and light weight pipe was introduced, that reduced the cost of installation. Since World War II the use of sprinkler irrigation has expanded rapidly, and the revolving head sprinklers are commonly utilized for the applicator.

The distribution profiles are different for nozzles working under different pressures. The amount of water measured in the catchment cans will not be the same, if measured at different points from the sprinkler along the radius. If the sprinkler works on the slope of a hill, the distribution of water is not the same as that on flat ground. The sprinkler is usually working in the field under variable wind conditions. The wind velocity will be a positive component to the jet of water in the direction of the wind, to effect an extension of the normal distribution profile.

Initial tests were conducted inside the laboratory to avoid wind effects. Only medium pressure sprinklers were used. The data for the distribution profiles were collected for circular nozzles, 11/64 inch and 7/32 inch diameters, under pressures ranging from 20 to 60 psi. The distribution profiles show that the amount of fall-out near the sprinkler is greatest due to the action of the actuator. Generally speaking, the fall-out decreases gradually as we approach the extremity of the profile.

The effect of slope upon distribution profile was observed on 5 percent and 10 percent slopes. The amount of precipitation of water was higher on up-slopes, as compared to the flat ground. When working on up-grades, the length of trajectory was shortened. After plotting the precipitation profiles on the flat, 5 percent, and 10 percent slopes for different nozzles and for different pressures, the precipitation profiles for the in-between slopes could be interpolated.

The effect of wind velocities on the water distribution was studied in tests conducted in the open field. Both the length of the trajectory, and the distribution profile were affected considerably by different wind velocities.

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ACKNOWLEDGMENTS

The author is extremely grateful to Dr. Hashim Amir Ali, principal of the College of Agriculture, Osmania University, Hyderabad, India, who had recommended to Dr. A. W. Farrall, Head of the Department of Agricultural Engineering, that he be admitted to Michigan State University for graduate work. Dr. Farrall was very kind to me during my stay and, in fact, his consideration has made it possible for me to complete my graduate work. The author is also grateful to Professor Ziauddin Ansari, principal of the College of Engineering, and to Dr. Bhagvantham, Vice-Chancellor of the Osamania University, who granted me leave for my higher studies in the United States.

The author was very much pleased to work under Professor E. H. Kidder of the Department of Agricultural Engineering, who, as his major professor, has shown constant interest in the results of his research. The author expresses his sincere thanks to him.

He is very much indebted to Professor Roland Wheaton for his valuable suggestions and guidance.

Lastly, the author is very much grateful to his wife, Rehana Hameed Quadri, who took the trouble of staying in the laboratory with her son Mahboob Quadri, during experiments, and assisted him in recording the test results and writing this thesis.

VITA

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INTRODUCTION

Presentation of the Problem

Rotary sprinkler irrigation systems are widely used for irrigation purposes on most soil types, and where topography is unfavorable for direct surface irrigation. In 1946 less than 250,000 acres were irrigated by this method, however the acreage is now increasing at an estimated rate of 500,000 acres a year. Sprinkler irrigation eliminates a very costly and unpredictable farming hazard in the humid areas, that of insufficient moisture at critical growth periods.

The rotating head or circular spray sprinklers have come into favor since the development of the light-weight, portable, quick-coupler pipe. The advantage of this sprinkler over other types is its ability of applying water at slow rates while using relatively large nozzle openings. There are four types of water applicators available for overhead irrigation:

a) perforated pipe

b) fixed nozzle attached to oscillating pipe

c) rotary head sprinklers

d) fixed head sprinklers

The earlier sprinkler systems were fixed nozzle pipe type. Sprinkler systems operate under a wide range of pressures ranging from 5 psi to over 100 psi. The operating pressure is in part determined by power costs, area to be covered, type of sprinkler, and the crop being sprinkled. Low pressures range from 5 to 15 psi, medium from 16 to 60 psi, and high pressures from 60 to 100 psi. Pressures well above 100 psi are designated as "hydraulic." Sprinklers in the low pressure range have small area coverage and relatively high application rates. Their use is generally confined to soils having infiltration rates of more than 1/2 inch per hour during the irrigation. Medium pressure sprinklers cover large areas, have a wide range of precipitation rates, and the water drops are well broken up. High pressure sprinklers area coverage and precipitation rates are higher than for the moderate or medium pressures. Application rates of 0.20 inches per hour are minimum rates with rotating sprinklers. This slow rate is desirable on soils of low infiltration rates.

On sloping lands, erosion by poorly controlled flowing irrigation water may be serious. The distribution of water is not uniform and there may be considerable water loss. As much as 50 percent of the water may be lost on slopes of 5 percent or more. Sprinkler irrigation can be applied to most sloping cultivated fields with no water loss through run-off and a minimum of soil erosion.

The distribution of water depends primarily upon the diameter of the nozzle on the sprinkler, the pressure, and the angle of incidence. A different distribution profile is obtained for each combination of the nozzle, or nozzle size and pressure. Ideally, water should be distributed uniformly over the entire area to be irrigated. Since rotating sprinklers cover circular areas, some overlapping will be necessary for complete coverage of the area under irrigation, but does not result in ideal distribution. The degree of uniformity obtainable depends primarily upon the geometric pattern of the sprinkler. The pattern from a sprinkler head may be triangular in shape. This geometric shape provides nearly uniform depth, when properly overlapped with adjacent sprinklers.

If the sprinkler rotates at a uniform speed about a vertical axis in perfectly still air, the resulting pattern should be symmetrical about the center, and the rate of precipitation in all directions should be the same. In case the ground is sloping, the distribution profile will not remain the same.

The wind produces variable effects on distribution uniformity. The rate of precipitation is considerably changed, and the profile is distorted. A research project was initiated to study the effect of slope and wind on the distribution profile of a medium pressure rotary sprinkler.

Approach to the Problem

This study was conducted in two parts, the first, in the Land Development Laboratory of the Department of Agricultural

Engineering under no wind conditions, and the second, in the field under variable wind conditions. Only the medium pressure sprinklers were studied, because this size was popular with irrigators and it could be studied in a laboratory. An electric motor driven centrifugal pump was installed over a water sump to supply water at a maximum pressure of about 80 psi. Experiments were carried out on rotary sprinkler "A" at pressures of 20, 30, 40, 50. and 60 psi. The floor of the laboratory was essentially flat. The duration for each test at each pressure was one hour. Each test was replicated three times to determine the average value of the point distribution of water in catchment cans placed on a radial line from the sprinkler at two feet intervals. The effect of up-slope on the distribution of water was evaluated on 5 and 10 percent slopes in the laboratory.

REVIEW OF LITERATURE

Christiansen (1) explains that the wind is major factor in dislocating the distribution pattern. The area covered is considerably reduced. There is usually a high concentration of water near the sprinkler, in directions normal to the direction of wind, and a deficiency in the leeward direction. The patterns are very uneven, and there may be a few areas of heavy and a few areas of very low precipitation. During his experiments, the wind was observed at frequent intervals in order to estimate the approximate average direction.

Wiersma (2) made tests of wind effects on sprinkler patterns, and evaluated them in terms of uniformity coefficients. He concluded that

a) tall risers are superior to short risers,

b) high pressures are superior to low pressures, and

c) large quantities of water per nozzle result in better patterns than small quantities of water.

Christiansen (1) shows that the maximum depth of water applied is near the sprinkler and that the depth decreases gradually as the distance from the sprinkler increases. The uniformity of the distribution of water from the sprinklers varies greatly, depending upon the pressure, rotation of the sprinkler, and the wind. He concludes that a uniform application is possible with proper sprinkler patterns and with proper spacing of sprinklers. Sprinkler patterns are approximately conical, where a maximum application occurs near the sprinkler and decreases gradually to the edge of the area covered, and produces a fairly uniform application, when the sprinklers are not farther apart than 55 to 60 percent of the diameter covered.

McCulloch and Schrunk (4) mention that one of the most important preliminary design factors is to consider the wind. If higher than 6 miles per hour winds are encountered, it may be necessary to use twice as many sprinklers. If a 40-foot spacing is usually used, it may be necessary to put sprinklers every 20 feet on the lateral, and reduce the gpm discharge per sprinkler to half the amount, to maintain the same precipitation rate as with the 40-foot spacing.

Bilanski (6) states that the amount of fall-out of water near the sprinkler was considerably greater than further out on the trajectory. Operating a medium pressure sprinkler at low pressures generally give unsatisfactory distribution profiles. There was also a decrease in the mean drop size and an increase in the maximum trajectory distance as the pressure was increased from low to more normal operating pressures.

LABORATORY EXPERIMENTS - APPARATUS AND METHODS

Apparatus

Pump

A 10 H.P. electric motor driven horizontal centrifugal pump was used for supplying water under pressure. The pump was rated at 150 gallons per minute, at 150 foot head. The pump and motor unit were installed on top of a concrete water tank. (Figure 1)

Delivery of Water to Sprinkler

The discharge side of the pump was connected to a pressure regulator drum (Figure 1). A globe valve was placed between the pressure drum and the pump. A one-inch diameter discharge pipe connected the bottom outlet of the drum to the sprinkler. The working pressure on the sprinkler was adjusted through a globe valve, included in the pipe line between the pressure drum and the sprinkler. (Figure 3)

To ensure the verticality of the sprinkler riser, an angle iron was welded to the horizontal G. I. pipe. (Figure 2) The laboratory floor was quite flat, therefore when this angle iron piece was placed on the floor, the riser pipe of the sprinkler was essentially vertical. The pipe connections, angle iron, riser pipe, pressure gauges, and the sprinkler used in the tests are illustrated in Figure 3.

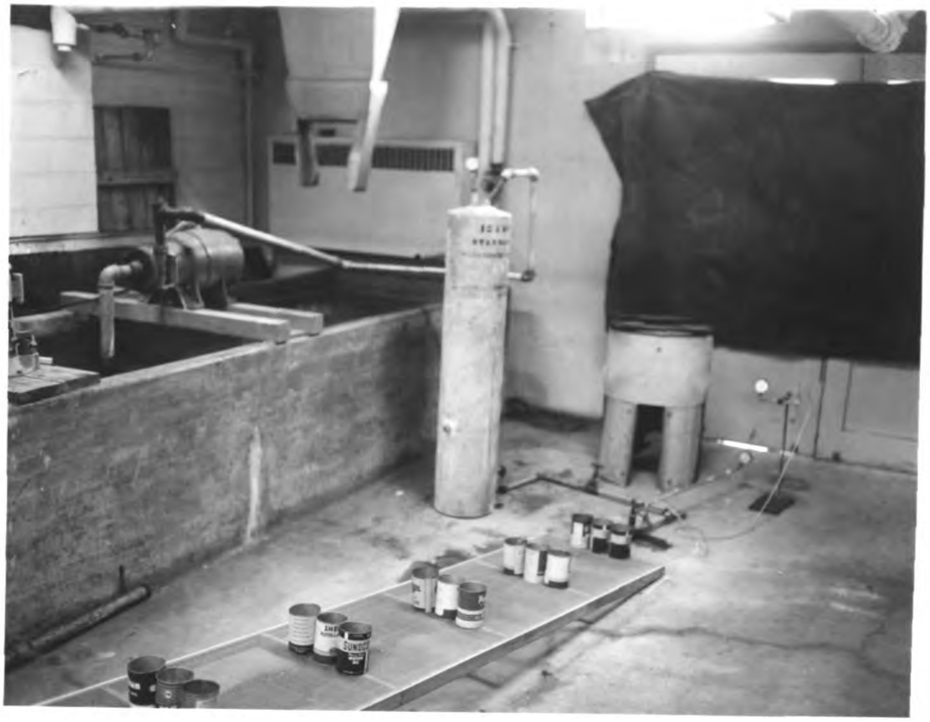


Fig. 1. Storage tank, pump unit and pipe connections to pressure drum.

Fig. 2. Angle iron welded to the pipe assures the verticality of the riser pipe.

Fig. 3. Pipe connections from pressure drum to the sprinkler, pressure gauges on the sprinkler and the sprinkler shield.

Pressure Gauges

Two pressure gauges were required, one was placed on the pressure drum, and the other at the sprinkler. The gauge at the pressure drum was scaled from zero to 100 psi. It was used to regulate the working pressure of the drum. The pressure gauge at the sprinkler gave the actual working pressure of the sprinkler. It was calibrated from zero to 60 psi. Its calibration was usually rechecked weekly with the Standard Pressure Gauge Tester.

Sprinkler Shield

As there was no wind in the laboratory, the water profile in each direction could be considered to be the same. The water profile was studied in one radial direction from the sprinkler. To protect the walls of the laboratory from splashing water, a 55-gallon oil barrel with one end removed was used to cover the sprinkler. A slot about 6 inches wide and 20 inches high from the floor was cut in the barrel. The jet of water from the rotation sprinkler could escape through this slot to sprinkle the test area. (Figures 3 and 6). A white circular line is shown on the floor around the sprinkler in Figure 2 to denote the position of the sprinkler shield.

Anti-Splash Device

The sprinkled water was to be collected at known distances along a radius from the sprinkler. To minimize the splashing effect of the water, a screen covered frame was placed under the water catchment cans. The screen was fitted on wooden frames, 2 feet wide and 10 feet long. The overall length of the screen sections placed end to end was about 50 feet. (Figure 6)

Water Measurement

The method of collecting water was to place one quart oil cans, with their tops cut out, on two foot centers upon the screen as shown in Figures 3 and 6. The tops of the cans under zero slope conditions were placed at the same level as the sprinkler nozzle. Two water measurement cans were placed side by side at each station and the average measured quantity was recorded. The duration of each run was one hour, the quantity of water in the cans was measured immediately. Each experimental test of a pressure and nozzle diameter combination was repeated three times to determine the average quantity of water received at each catchment point on the radius.

A cubic centimeter graduated cylinder was used to measure the water collected in the cans. The quantity of water collected in each can depended upon its depth and cross sectional area. To convert the quantity of water collected in the can, into inches of precipitation, the following relation was calculated:

one milliliter of water in oil can =

0.005 inches depth of water

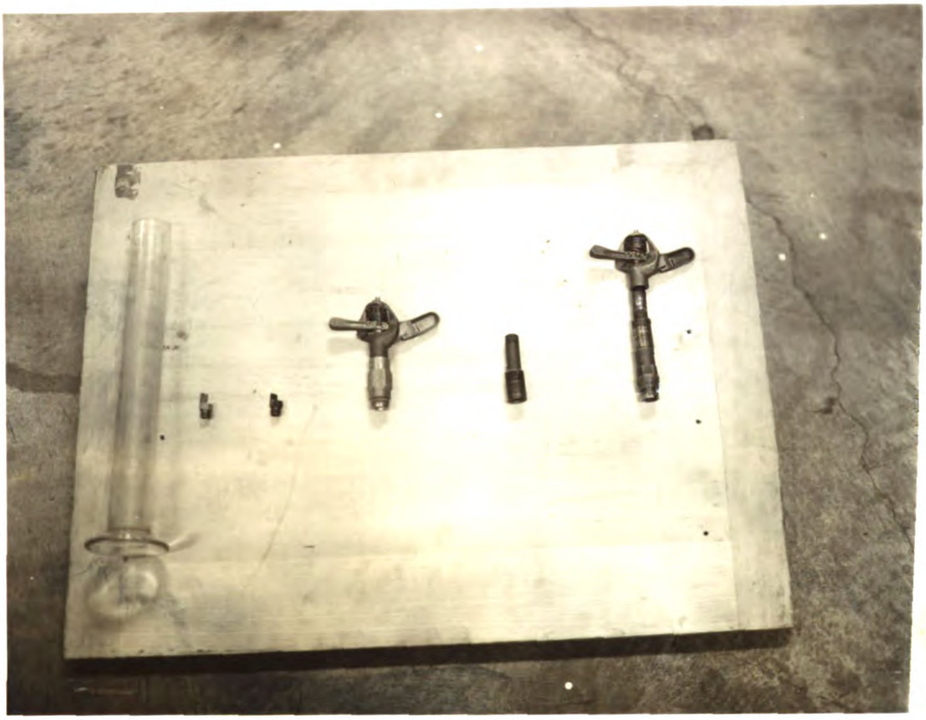


Fig. 4. Volumetric graduated cylinder, 11/64-inch and 7/32-inch diameter nozzle, sprinkler A, and bent riser pipe alone and attached to the sprinkler.

Sprinkler

In this study only rotary sprinklers A and B were used. These rotary sprinklers are driven by oscillating arms actuated outward by the jet of water, and brought back through the jet by a torsional spring to cause an impact against the sprinkler. Thus the rotating member is propelled around by the regular impacts. Individual sprinklers rotate at slightly different rates. Sprinklers type A, with nozzles of 11/64" diameter, 7/32" diameter, the riser pipe, and the volumetric graduated cylinder are shown in Figure 4. Sprinkler A had an outlet for one nozzle; while sprinkler B had outlets for two nozzles. One outlet on sprinkler B was plugged during operation. The rate of rotation of the sprinklers varied with different pressures and nozzle diameters. It was observed that the sprinklers do not rotate at a constant velocity. This variation may be due to variable function in the bearings.

Forms of Nozzles

Nozzles usually have a circular cross section and may either converge uniformly to a short parallel neck at the orifice or have a convergence which becomes more gradual as the outlet is approached. As stated by Gibson (9) the

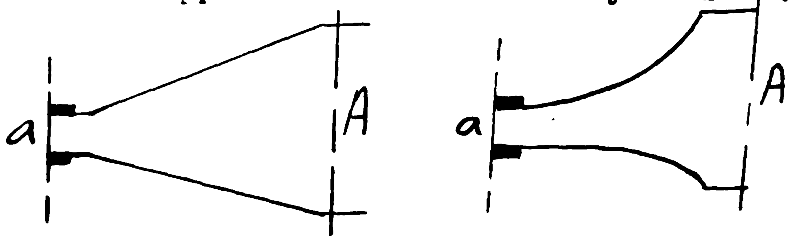


Fig. 5. Nozzle cross sections along a lineal axis.

coefficient of contraction of the type (2) is unity and the coefficient of discharge about 0.98. The efficiency of the nozzle depends entirely on the value of its coefficient of velocity. The velocity of flow through the nozzle at the end of the pipeline can be expressed

$$v_a \sqrt{\frac{4.6 \times P \times g}{1 + K - \frac{a^2}{A^2}}}$$

where P = pressure....psi. at the entrance of nozzle

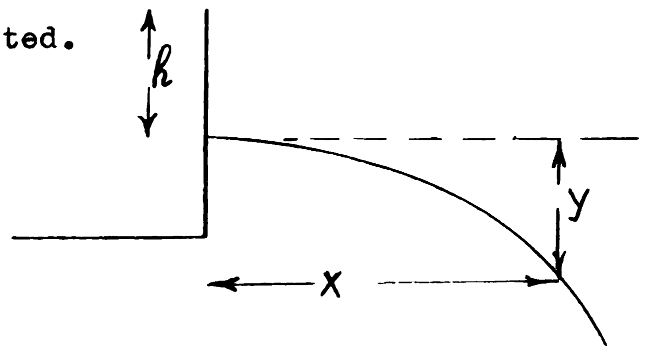
K = constant, approximately = 0.50

a and A = areas on both sections

Va = the velocity the jet of water from the orifice.

Bilanski (6) prefers type (1) to obtain the best distribution pattern for sprinkler irrigation.

A brief study of the jet of water coming from an orifice is presented.



Suppose there is an orifice in the vertical plane of the chamber. Keeping h constant, imagine a drop of water shooting from the orifice in the form of a jet, and travels a distance X horizontally and a distance y vertically. The drop of water that shoots out horizontally follows a smooth curve. Taking any point on the curve, if v = velocity

Coefficient of velocity $C_v = \sqrt{\frac{x^2}{4yh}}$

and velocity $v = C_v \sqrt{2gh}$

Applying this theory on a sprinkler, where the nozzle is at an angle, suppose the issuing jet makes an angle α with the horizontal.

$$x = V \cos\alpha \, t$$

$$y = 1/2 \, g \, t^2 = v \sin\alpha \, t = x \tan\alpha$$

on substituting this relation

$$v = \sqrt{\frac{g \, x^2 \, \mathrm{Sec}^2\alpha}{2 \, (y + x \tan\alpha)}}$$

Moreover by the following formula we can calculate the distance travelled of a droplet outgoing from the sprinkler at a certain angle.

$$x = \frac{v^2 \sin 2\alpha}{g}$$

where v = velocity of the droplet at the nozzle

α = angle of inclination of the nozzle.

Thus we understand that the distance travelled by the jet depends upon its velocity and the angle of inclination.

By the increase of α, the range x will also increase.

x will be maximum when $\sin 2\theta = 1$

$$2\theta = 90^\circ \quad \therefore \quad \theta = 45^\circ$$

The range of the nozzle will be maximum when the angle of rise of the nozzle is 45°. In the above formula for the calculation of the range or the length of trajectory, the air friction is not taken into consideration.

Methods and Discussion

Distribution Profiles on Flat Ground

The 50 foot section of screen was placed flat on the floor, two cans were placed on it side by side at 2 foot intervals. The opening of the sprinkler shield was closed with a curved steel sheet. The first experiment was conducted on sprinkler A using a 11/64 inch diameter circular nozzle. The working pressures were 20, 30, 40, 50 and 60 psi and the angle of inclination of the nozzle for sprinkler A was 22 1/2 degrees. The distribution profiles show the range of water distribution for different pressures, and also the amount of precipitation in inches per hour at two foot intervals along a radius from the sprinkler, under no wind conditions. (Figure 7)

The distribution of water is fairly uniform between 7 feet and 31 feet, except in the case of the distribution profile at 20 psi which shoots up to a high peak at 31 feet distance, which is not similar to the other profiles. There is obviously the effect of a low nozzle velocity and the resultant insufficient break up of the jet as it passes through

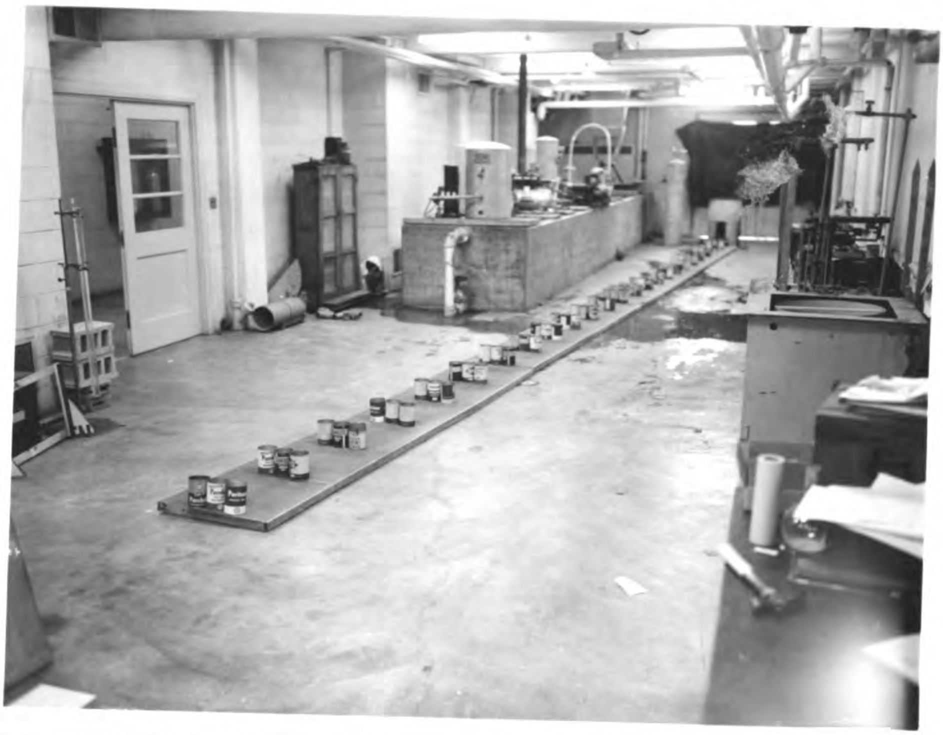


Fig. 6. Sprinkler shield placed over the sprinkler and 50-foot length of anti-splash screen with catchment cans in place at 2-foot intervals.

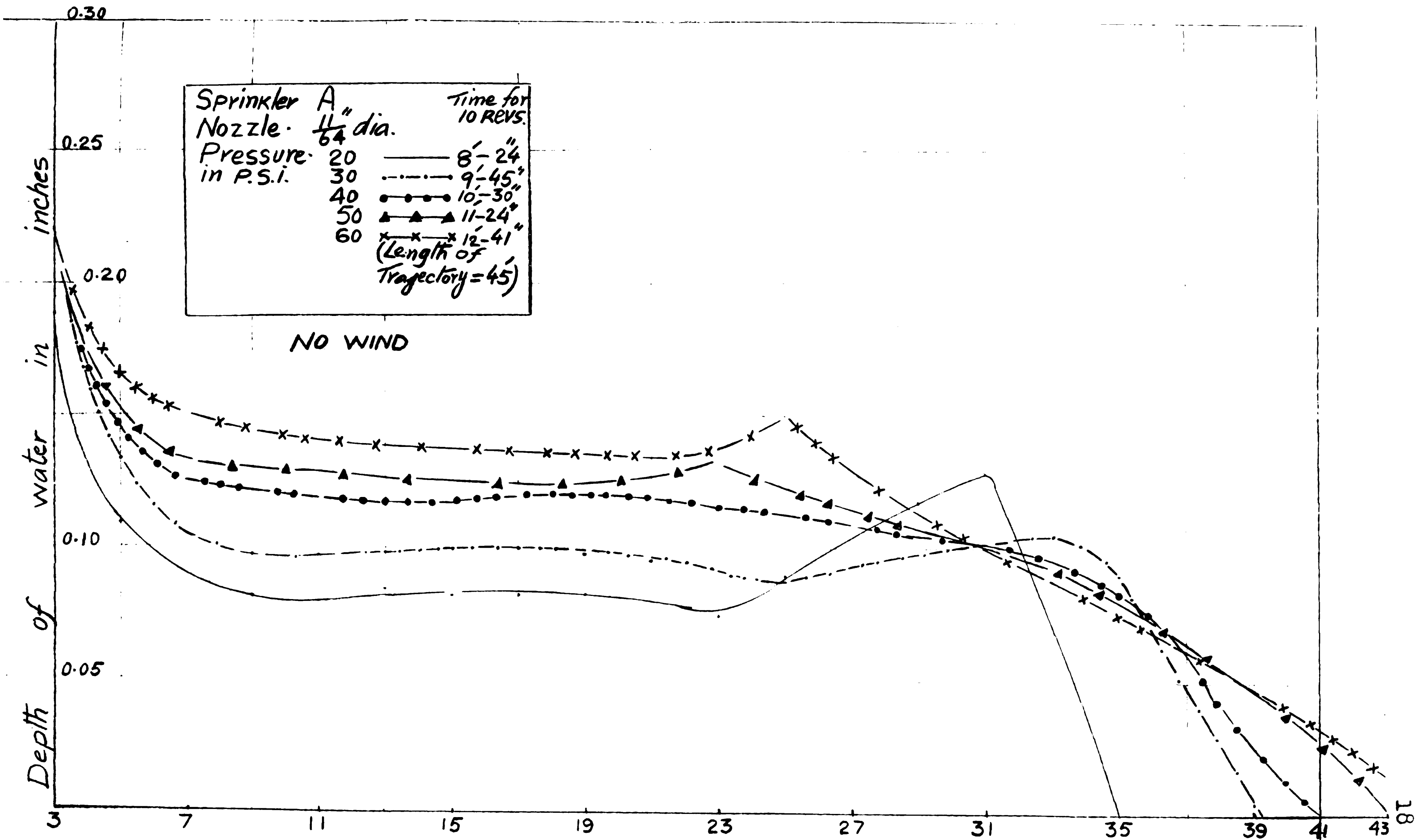


FIG. 7 Distribution profiles on flat Screen using 11/64" dia. nozzle of Various pressures for one hour.

0.30

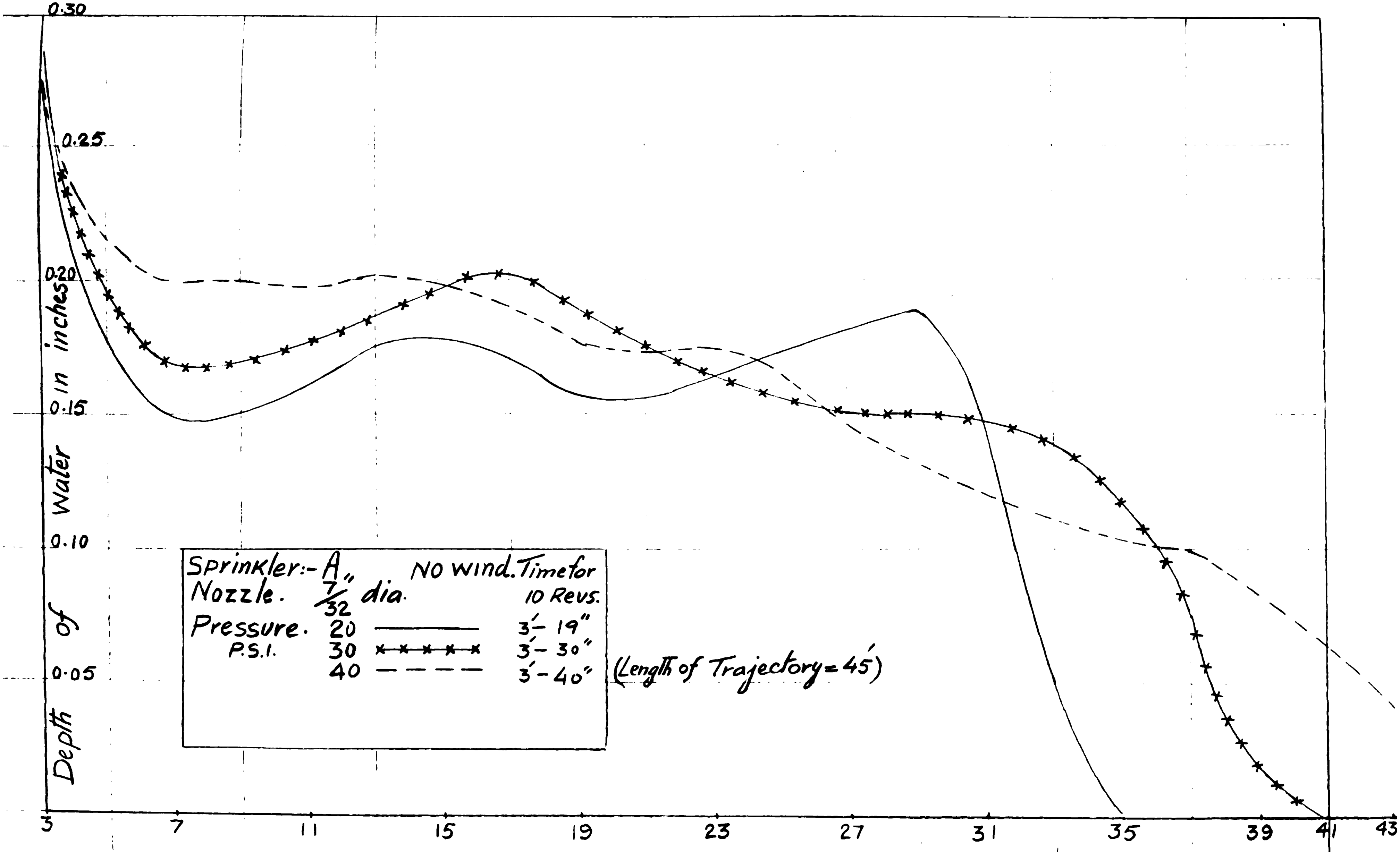


FIG. 8 Distribution profiles on flat, using $\frac{7}{32}$" dia. nozzle on various pressures for one hour.

the air. The amount of precipitation gradually increases as the pressure is increased, and the range of trajectory increases from 35 feet to 45 feet. Average precipitation with the 11/64 inch diameter nozzle at 20 psi is about 0.094 inch per hour. It can be increased to 0.134 inches per hour at 60 psi. Referring to all the profiles, we find a common point at 31 feet distance through which all the profiles pass, except the profile for 20 psi. The profiles also show that there is a great accumulation of water very near to the sprinkler. Bilanski (6) states that when the oscillating arm was used to rotate the sprinkler, the amount of fall out of water near the sprinkler was great. The rate of sprinkler rotation was noted by stop watch on different pressures, this is shown with the distribution profiles. It changes slightly with different pressures. Similar tests were carried out with a 7/32 inch diameter nozzle in the same no A sprinkler, working on pressures of 20, 30, and 40 psi. (Figure 8) Referring to these profiles, the 7/32 inch diameter nozzle at 20 psi has a fairly uniform distribution approaching 0.170 inch of water per hour for a distance of from 5 to 29 feet, then the amount of application decreases rapidly. The effect of the actuator arm results in a peak at 15 feet, and the breakup of the jet results in another peak at 29 feet. The overall range at this pressure is 35 feet. In the same way for 30 psi. The average distribution of water is about 0.172 inch

Fig. 9. Position of the screen on
5 percent slope.

Fig. 10. Position of screen on
10 percent slope.

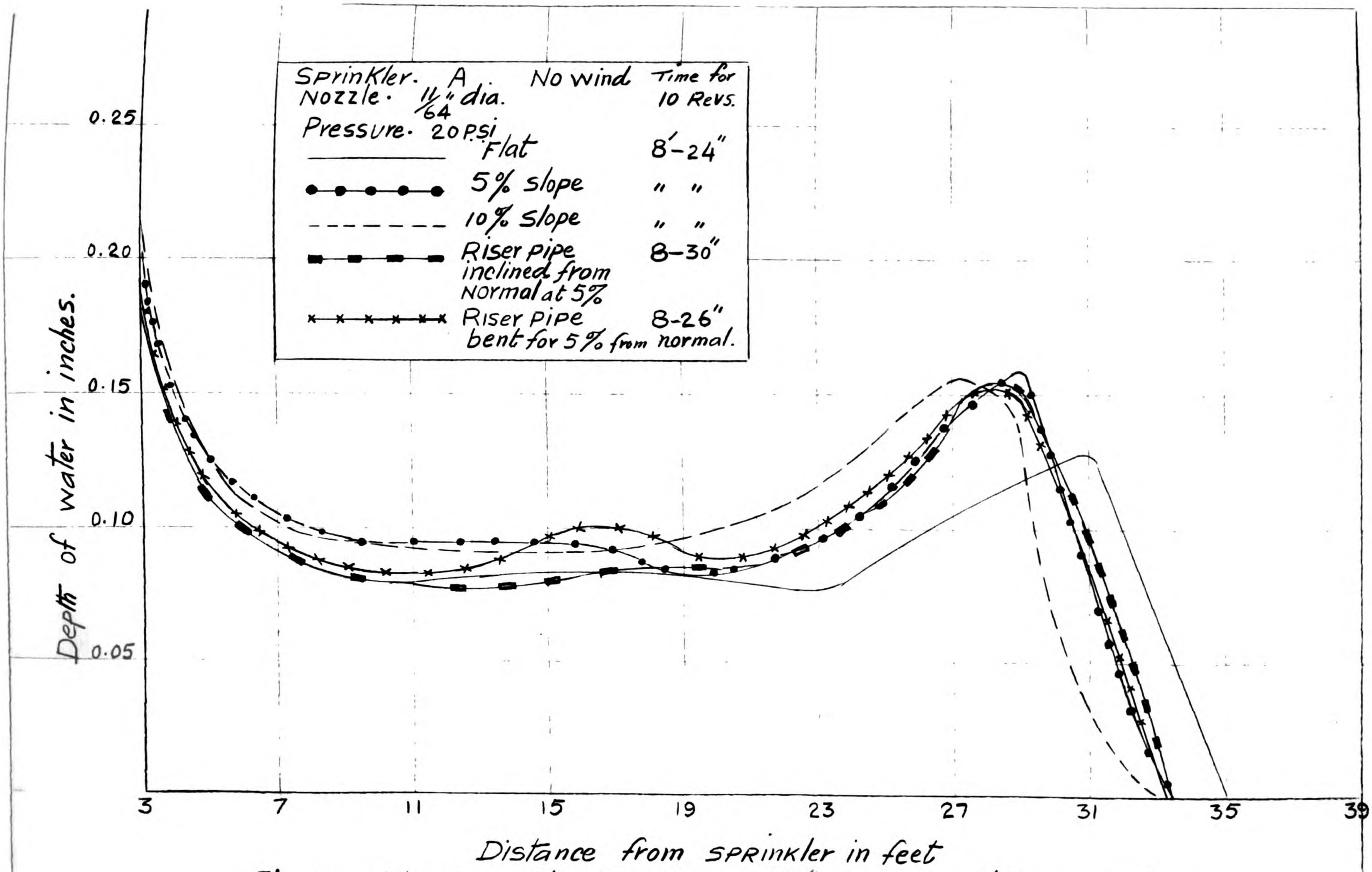


FIG. 11 Distribution profiles at 20 P.S.I. using 11/64" dia. nozzle on flat, 5%, 10% slopes, and when the riser pipe was inclined from Normal at 5% slope and when riser pipe was bent for 5% slope.

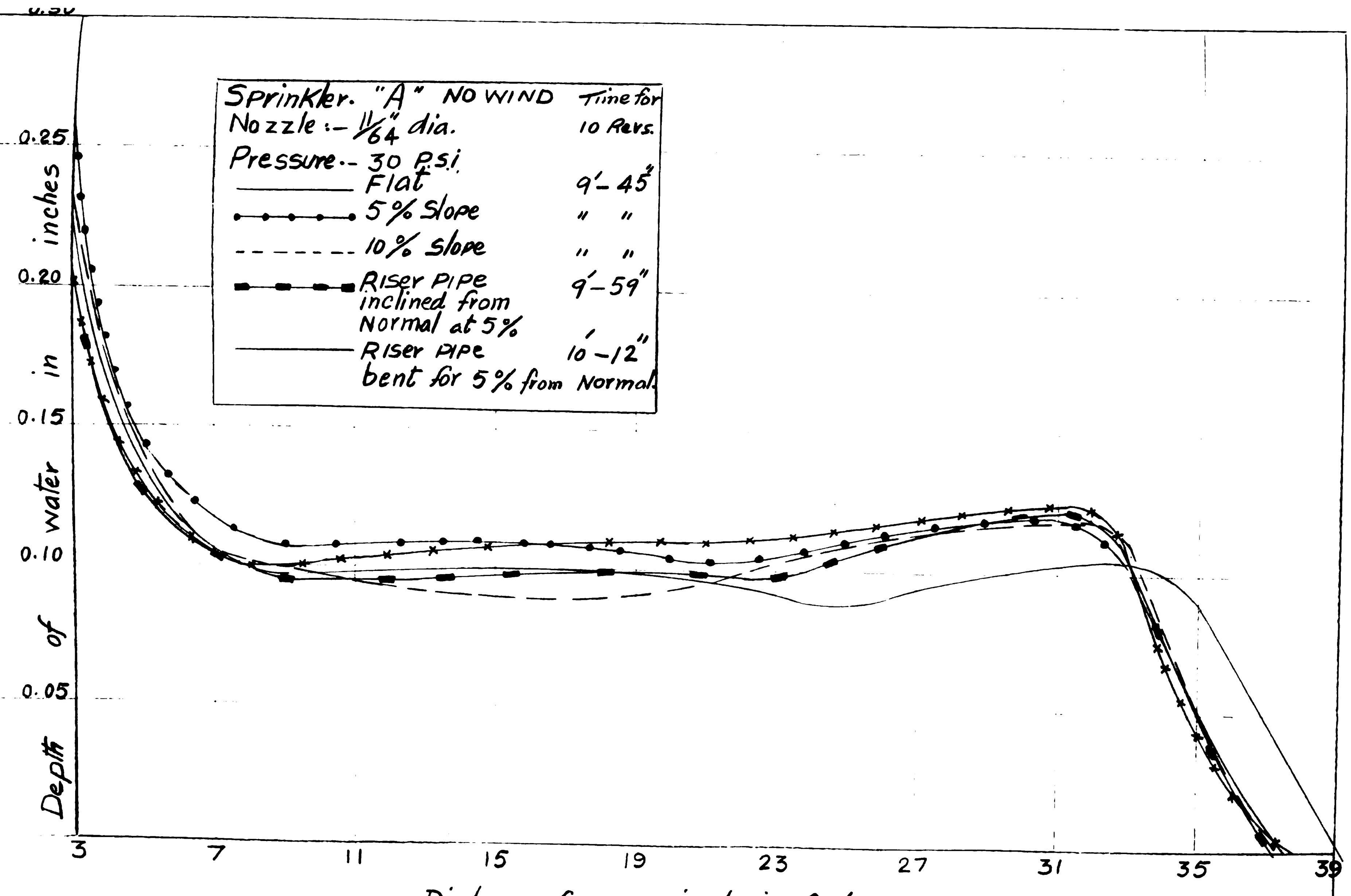


FIG. 12 Distribution profiles at 30 psi using 11/64" dia. nozzle on flat, 5%, 10% slopes, and when the riser pipe was inclined from normal at 5% slope, and when riser pipe was bent for 5% slope.

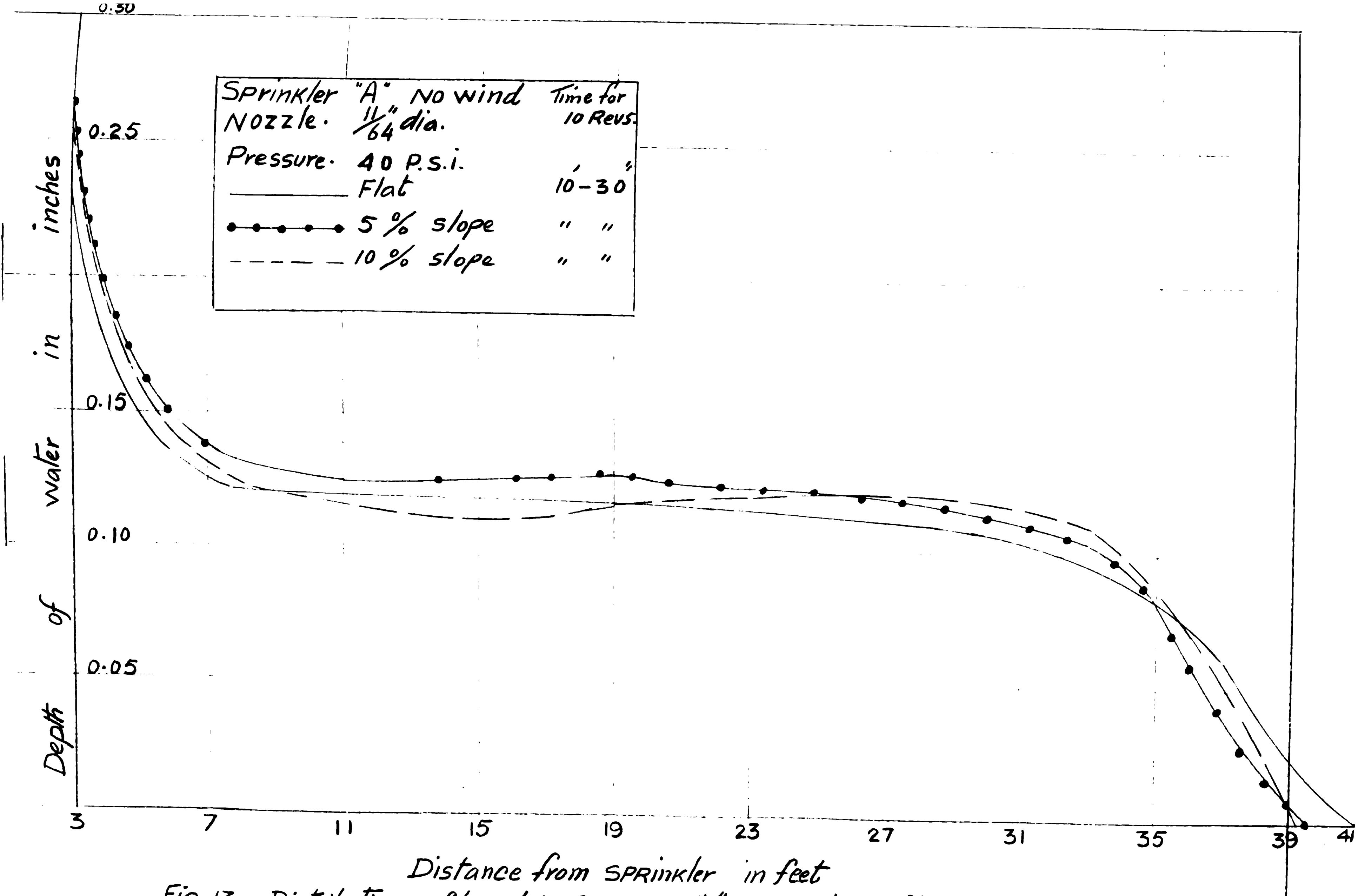


FIG. 13 Distribution profiles at 40 Psi. using 11/64" dia. nozzle on flat, 5%, 10% slopes.

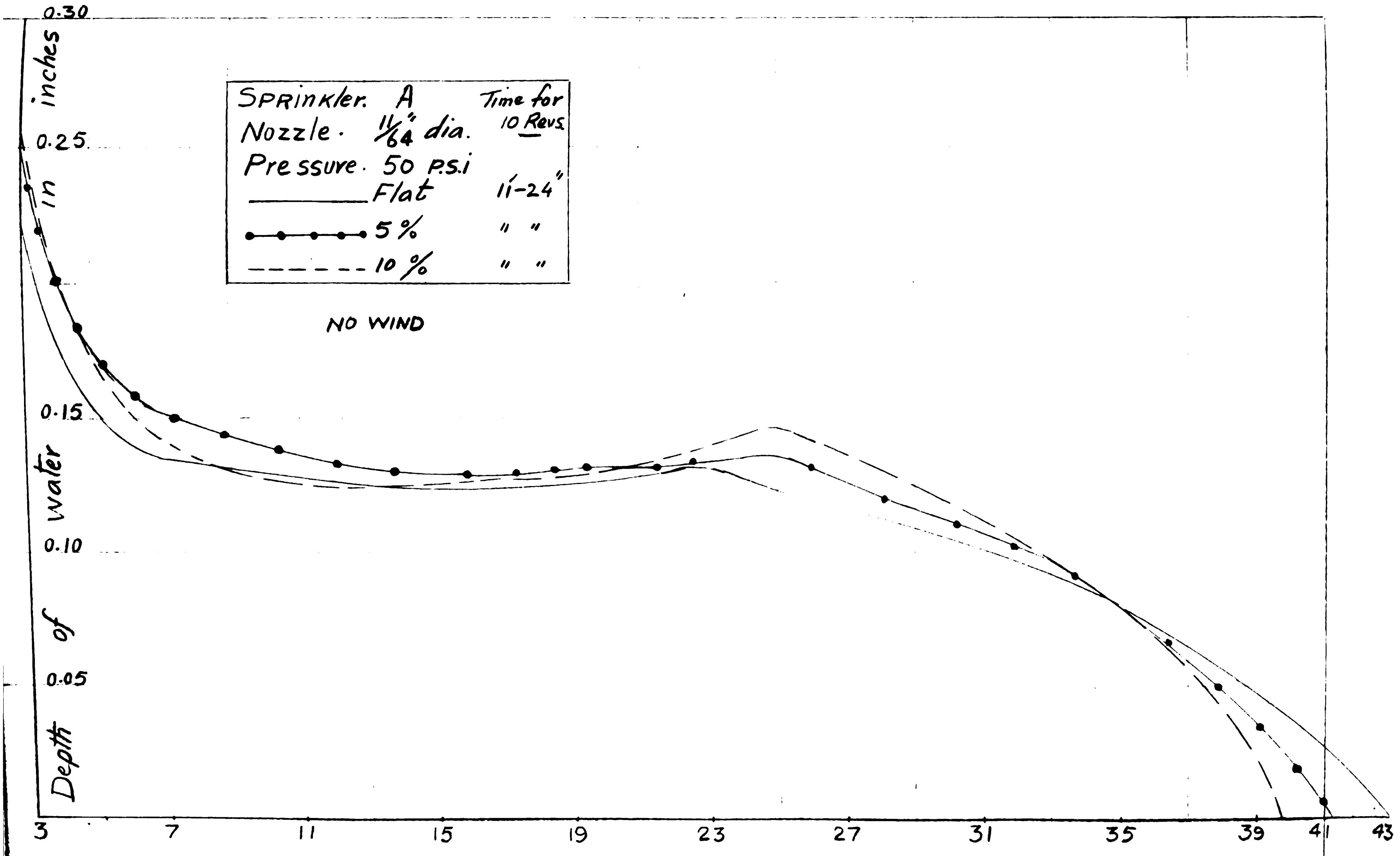


FIG. 14 Distribution profiles at 50 p.s.i. using 11/64 inch dia. nozzle on flat, 5%, 10% slopes.

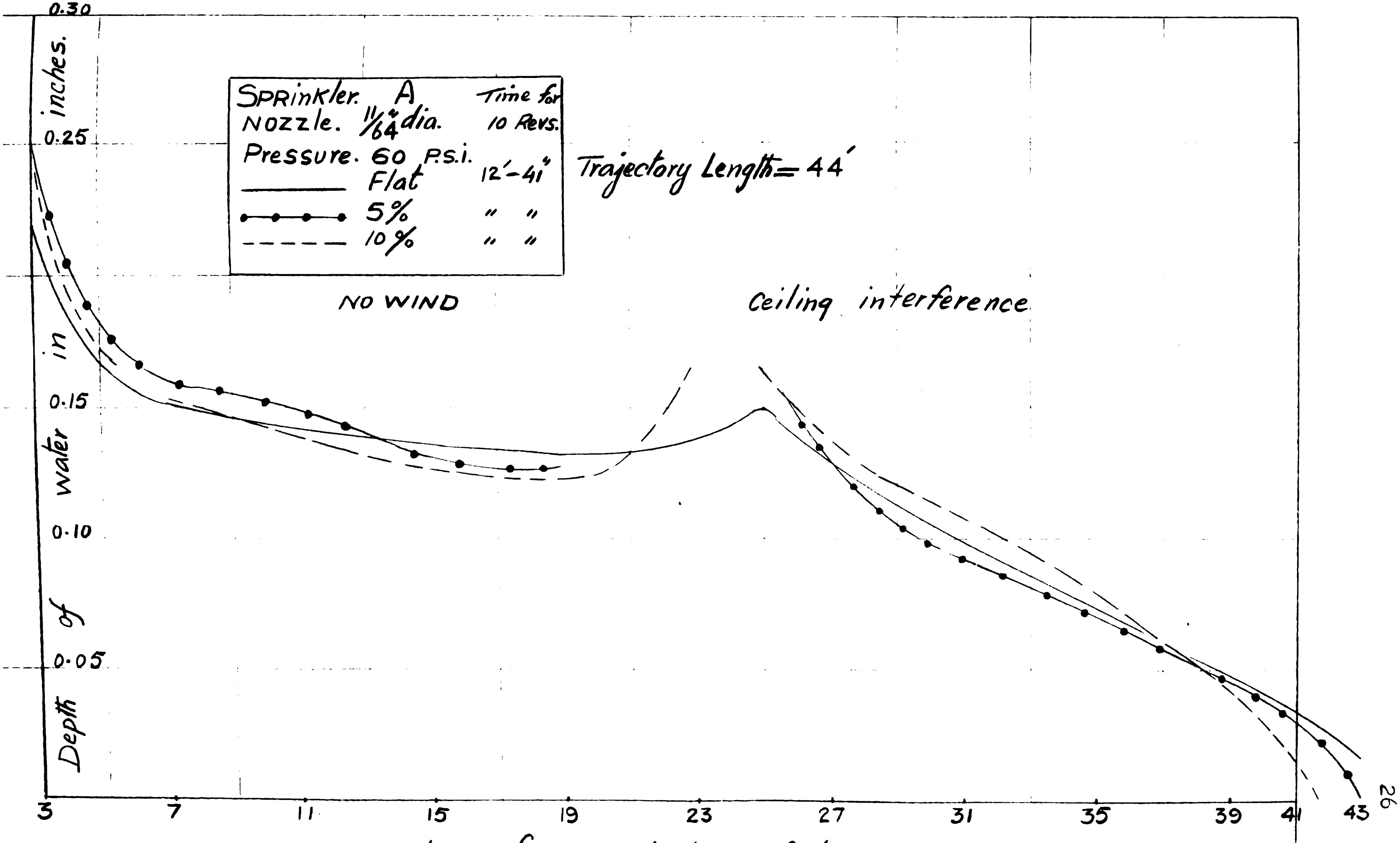


FIG. 15 Distribution profiles at 60 psi. using 11/64" dia nozzle on flat, 5%, 10% slopes.

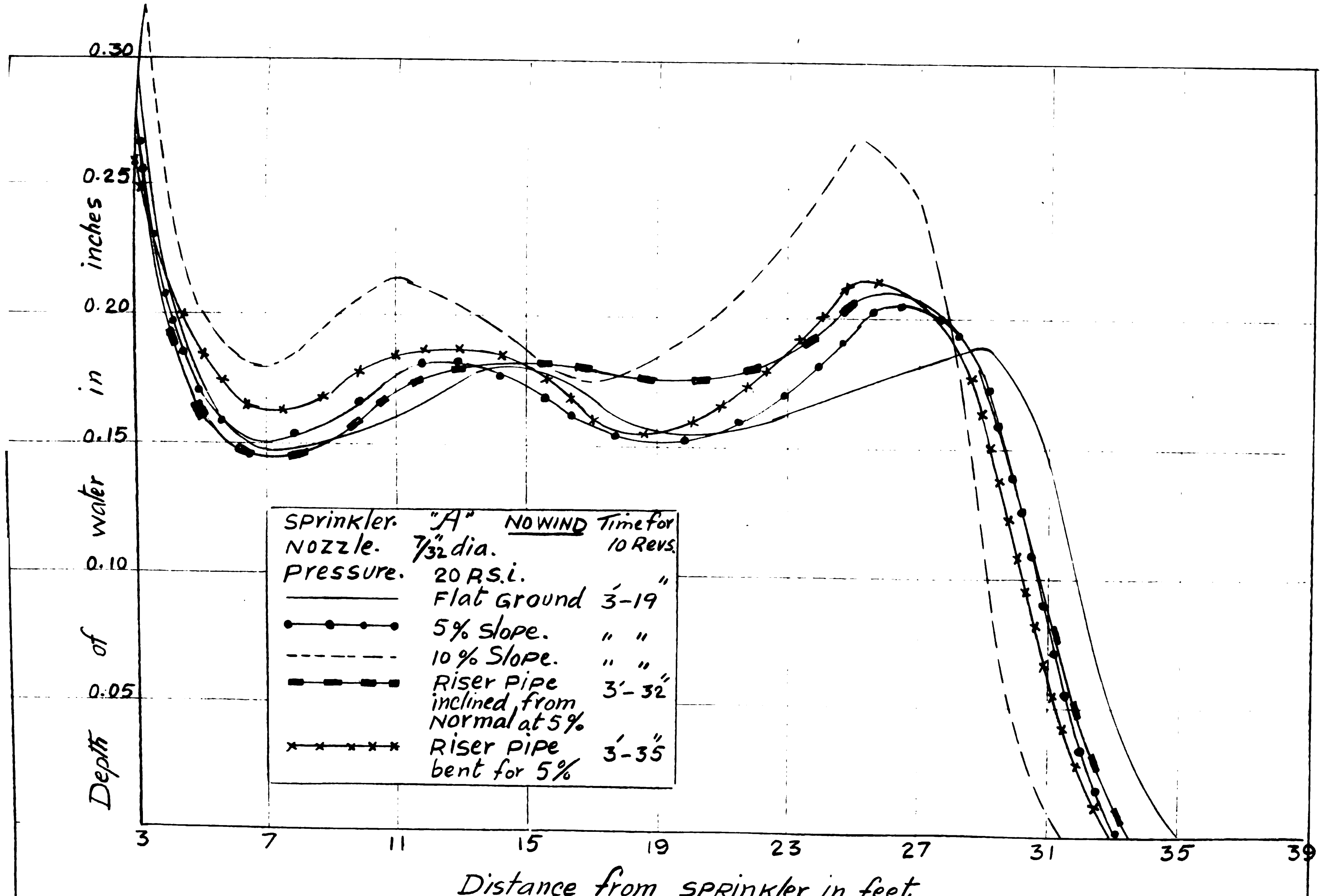


FIG. 16 Distribution profiles at 20 P.S.I. using 7/32" dia. nozzle on flat, 5%, 10% slopes, and when the riser pipe was inclined from normal at 5% slope, and when riser pipe was bent for 5% slope.

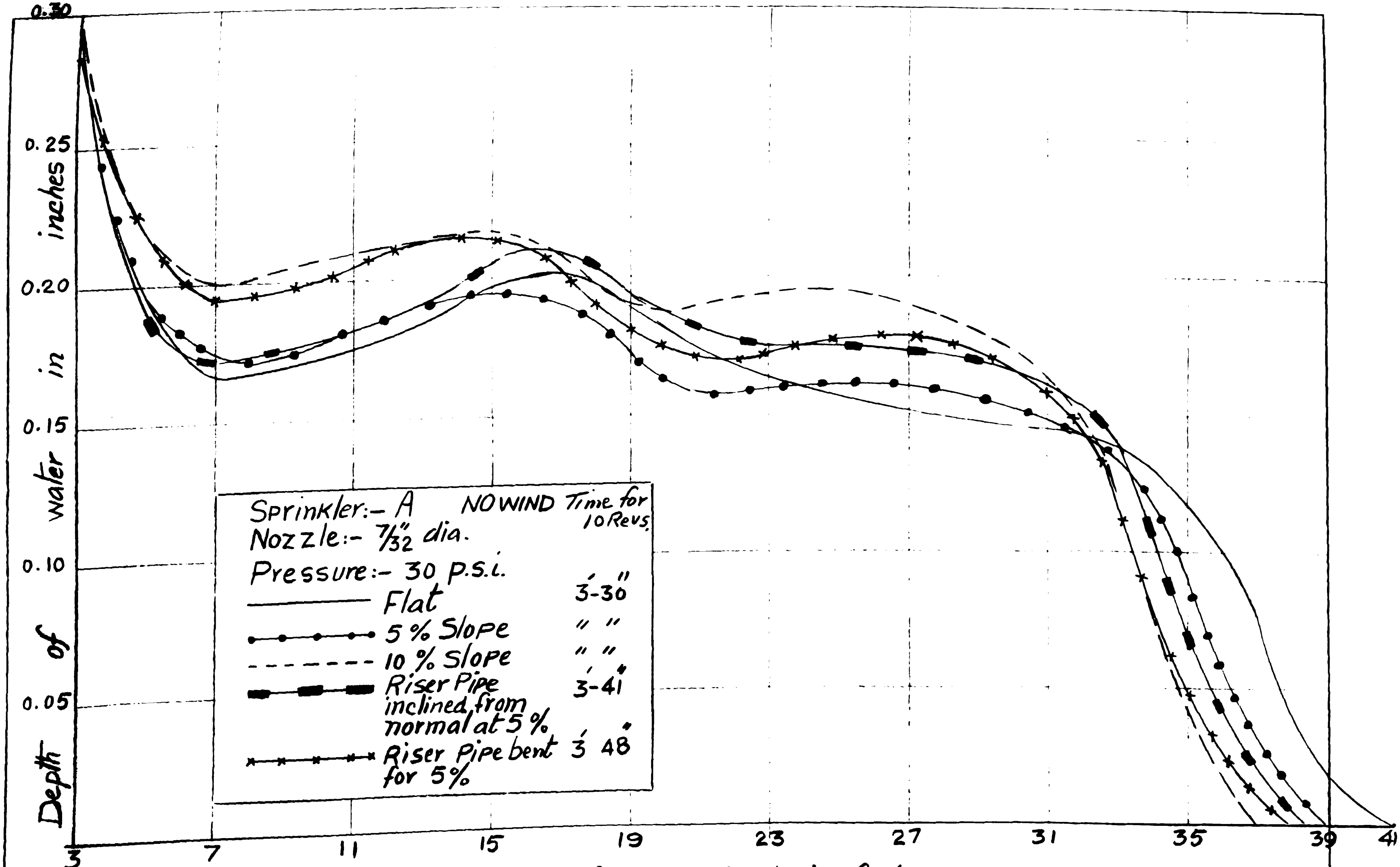


FIG. 17. Distribution profiles at 30 psi using 7/32" dia. nozzle on flat, 5%, 10% slopes and when the riser pipe was inclined from normal at 5% slope, and when riser pipe was bent for 5% slope.

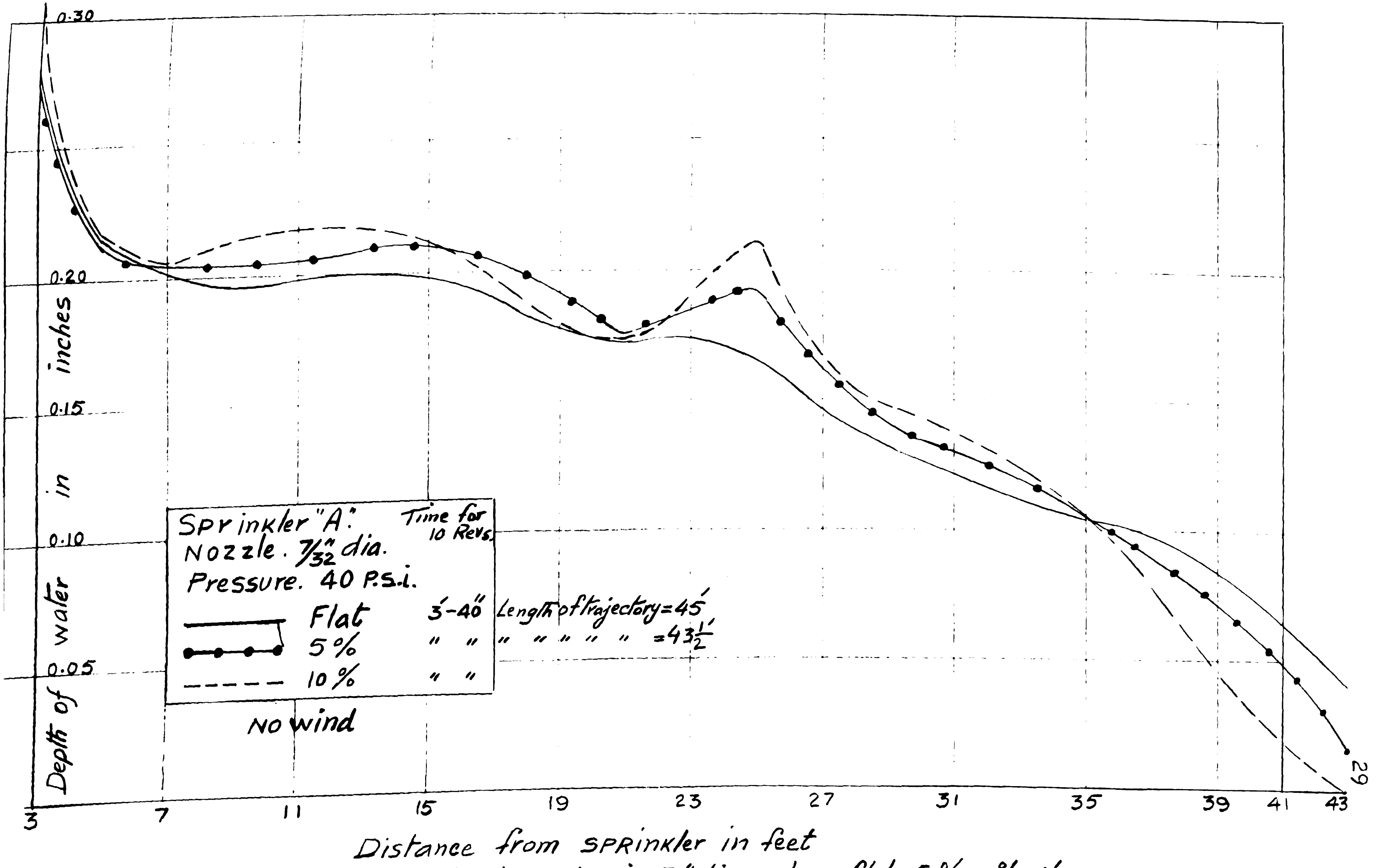


FIG. 18 Distribution profiles at 40 p.s.i. using 7/32" dia. nozzle on flat, 5%, 10% slopes.

per hour in a distance range of 5 feet to 31 feet from the sprinkler and beyond this the amount of water collected reduces rapidly to zero at 41 feet. The distribution profile extends 6 feet beyond the profile with the 20 psi pressure. At 40 psi the distribution profile is not uniform. The amount of application keeps falling gradually from the sprinkler to the end of the trajectory at 45 feet. This profile is most desirable. In order to obtain a reasonable uniformity of application, water from another sprinkler must be added to the same area. This method of over lap is explained by McCulloch and Schrunk (4).

Distribution Profiles on Five Percent Slope

To study the effect of slope on water distribution, the 50 foot screen was tilted at a desired slope. Two slopes of 5 percent and 10 percent were studied. Wooden frames were made to support the screens on these slopes (Figure 9). Empty oil cans were used to collect the water at two foot intervals along a radius. Two cans were placed side by side to obtain the average quantity of water received at that point. The sprinkler was operated at 20, 30, 40, 50 and 60 psi using a 11/64 inch diameter nozzle. Each test was run for an hour and replicated three times. The same series of tests was repeated for a 7/32 inch diameter nozzle on the pressures 20, 30 and 40 psi. Figures 11 through 18 illustrate the distribution profiles on 5 percent, and 10 percent up slopes, when the sprinkler was operated in the vertical plane. The distribution profiles peaks on the slopes are a few hundredths higher than the distribution profile peaks on the flat ground. The peak that formed at 31 feet for 20 psi on flat ground, was shifted back to 29 feet on the 5 percent slope and 27 feet on the 10 percent slope. When the 11/64 inch diameter nozzle was used (Figure 11), the length of the trajectory on the flat ground was longer than that of the 5 percent and 10 percent slopes by about 2 feet. The amount of fall out of water near the sprinkler was considerably higher on the slopes than on the flat ground. This fall out decreased gradually along the trajectory, to a point about one-fourth or one-fifth the length of the trajectory. The precipitation peak value is far greater than the average value between 7 and 20 feet (Figure 11). Figure 12 illustrates the distribution profiles at 30 psi. The peak value is only a few hundredths greater than the average, so the precipitation between 9 and 31 feet is fairly uniform. The length of the trajectory on the flat was about 2 feet longer than on the 5 percent and 10 percent slopes. At 40 psi the amount of precipitation is fairly uniform between 7 feet and 33 feet (Figure 13). The profiles in Figure 15 are not true profiles, since the jet is partially striking against the ceiling. In those tests the water cans were placed on the slope, hence they were at right angles to the slope, instead of vertical. Therefore the projected horizontal area was less than the actual area of the existing

can. This might cause some change in the quantity of the water collection. A third can was placed side by side to the other two cans, but in a vertical position, while the other two cans remained at right angles to the screen. Tests were carried out at different pressures, and it was observed that the quantity of water collected in this third can was within one to two cubic centimeters of that in the other cans. This was negligible, and could be neglected.

<u>Sprinkler Riser at Right Angle to Five Percent Slope</u>

During the above mentioned slope tests, the sprinkler riser pipe was vertical which is often the case in a sprinkler irrigation system on flat land. Considering the 5 percent slope of the fields, or any other slope, the riser pipe will not be vertical, but at a right angle to the slope. To study the distribution profiles of this situation in the laboratory, the riser pipe of the sprinkler was placed perpendicular to the slope. The vertical angle of the nozzle, which was about 22 1/2 degrees, would be increased by a 5 percent inclination from the horizontal for up-slope conditions. The distribution profiles of the same sprinkler were recorded at the same pressures of 20 and 30 psi with 11/64 inch and 7/32 inch diameter nozzles. These distribution curves are shown in Figures 11, 12, 16 and 17. The distribution of water was almost the same as was found when the riser pipe was vertical, and sprinkling flat land, but only for a distance of about 21 feet from the sprinkler when 11/64 inch diameter nozzle was used. (Figure 11) Beyond this it was almost identical to the distribution on 5 percent slope by a vertical riser sprinkler. Moreover in the inclined position of the riser pipe the sprinkler oscillating arm will not be moving in a horizontal plane which could affect the uniformity of rotation rate.

Riser Pipe Bent

To study the effect of the change of vertical angle, the riser pipe was bent for a 5 percent inclination from the vertical and the sprinkler was fitted on the top. (Figure 4) In this way the vertical angle of the nozzle of the sprinkler was increased by 5 percent inclination from its original position. The vertical angle of the nozzle in this case will be the same as in the previous case when the riser pipe was tilted backwards. The distribution profiles are shown in Figures 11, 12, 16, and 17. The vertical angle of the nozzle in the down-slope direction will be reduced by 5 percent declination from its original position. With the riser pipe bent for 5 percent inclination on up slopes, and the sprinkler attached to it, tests were carried out at pressures of 20, and 30 psi. (Figures 11, 12, 16 and 17) These profiles are similar to those when the riser pipe was tilted backwards by 5 percent declination.

Distribution Profiles on Ten Percent Slope

The 50 foot screen was supported on a 10 percent slope from the sprinkler. (Figure 10) As previously explained, the empty oil cans were used to collect the water at 2 foot intervals from the sprinkler. Two cans were placed side by side to take the average quantity of water. The experiments were conducted on the sprinkler A for the nozzles 11/64 inch diameter and 7/32 inch diameter, on 20, 30, 40 and 50 psi. Each experiment was run for an hour and was replicated three times for an average, from which the distribution profiles were plotted. (Figures 11 through 18) Referring to the precipitation profiles, the distribution of water on 10 percent slope was higher than the distribution of water on 5 percent slope. The peak of the distribution profile on 10 percent slope was shifted two feet towards the sprinkler, when compared to the peak on the 5 percent slope, and the length of the trajectory which was 35 feet on flat position, was reduced to 33.25 feet on 5 percent slope, and to 33 feet on 10 percent slope. (Figure 11) Referring to the profiles in Figure 11, the distribution of water is fairly uniform from 6 feet to 21 feet, and then the amount of precipitation of water increases till it reaches the peak value at 28 feet, then decreases rapidly to zero at 33 feet. The profiles show a typical lower pressure distribution with a peak or ring effect at 28 feet from the sprinkler.

Referring to Figure 12 at 30 psi for 11/64 inch diameter nozzle, the precipitation profiles are all fairly uniform between 6 and 31 feet along the radius from the sprinkler, beyond this the amount of precipitation reduces rapidly to zero at 37 feet. In Figure 13 at 40 psi for 11/64 inch diameter nozzle, the precipitation profiles are relatively uniform from 7 to 33 feet from the sprinkler. For a pressure of 50 psi on the same 11/64 inch diameter nozzle, the uniformity of the precipitation profile was slightly distorted by a peak at about 25 feet from the sprinkler (Figure 14) but the length of the trajectory decreases from 43 feet on flat, to 41 feet on 5 percent slope, and 40 feet on 10 percent slope. As the pressure on the sprinkler increases, the length of the trajectory also increases, as shown in Figure 15, the length of the distribution profile on flat increased to 44 feet, when the same 11/64 inch diameter nozzle was used at 60 psi. The distribution profile on 5 percent and 10 percent slopes could not be completely recorded at 60 psi because of the jet, striking the ceiling of the laboratory. The distribution profile on 10 percent slope for 7/32 inch diameter nozzle on 20 psi was considerably higher than the profiles on the flat and 5 percent slope. (Figure 16). The peaks formed in case of flat at 15 feet, and 29 feet, were shifted towards the sprinkler to 13 and 27 feet on 5 percent slope and 11 and 25 feet on 10 percent slope.

Figure 17 shows the distribution profile on 10 percent slope for 7/32 inch diameter nozzle at 30 psi. There are two peaks at 15 and 25 feet from the sprinkler, but their values are approximately the same. The precipitation of water is fairly uniform between 5 and 29 feet from the sprinkler. The amount of fall out of water near the sprinkler is considerably greater than the fall out at points of greater distances from the sprinkler.

Tests were carried out for the same 7/32 inch diameter nozzle on 40 psi (Figure 18) on 10 percent slope. The distribution profile shows a peak at 25 feet from the sprinkler. The length of the trajectory which was 45 feet on the flat was reduced to 43.5 feet on 5 percent slope and to 43 feet on 10 percent slope. At this pressure the resulting water profile from the sprinkler head is mostly triangular in shape. This provides opportunity for nearly uniform depth of coverage, provided proper overlap from the adjacent sprinkler (4).

Sprinkler B could not be operated inside the laboratory for want of a higher ceiling.

FIELD EXPERIMENTS - APPARATUS AND METHODS

Effect of Wind on Water Distribution Profiles

The same tests that were carried out in the laboratory were repeated outdoors, under wind conditions. The practical use of the sprinkler is in the open field, to irrigate the crop when the wind may be blowing. Therefore the study of the effect of wind on the distribution profile is of vital importance. The data of the distribution of water was collected on an hourly basis. The tests were conducted mostly in the early evenings, when the wind velocity was low.

Apparatus and Methods

Location

The tests of the effect of wind velocity on the distribution profiles of the medium pressure rotating sprinklers were carried out on a fairly flat land behind the Agricultural Engineering Building. In the field experiments all of the three conditions of slope, flat, 5 percent, and 10 percent, were evaluated simultaneously during the same test. Three distribution profiles were recorded in a one-hour run.

Fifty foot screens, carrying empty oil cans, were placed in three directions for flat, 5 percent, and 10 percent slopes.

Fig. 19. Fifty foot screens placed in three directions for flat, 5 percent, and 10 percent slope.

Fig. 20. Five percent slope in foreground, flat to left, and 10 percent slope in the background.

(Figure 19) The sprinkler was placed at the center point of these three slopes. The 5 percent slope and the 10 percent slope are in the same line diagonally opposite, and the flat position of the screen was at a right angle to them. The general direction of the wind for most tests was southeast. Standing over the sprinkler, the bearing of the 5 percent slope was about 120 degrees, therefore the direction of the southeast wind was almost against the jet of water, sprinkling the 5 percent slope. The bearing of the 10 percent slope was about 300 degrees, as such the wind was pushing the jet of water forward when sprinkling on the 10 percent slope. The position of the sprinkler was made firm on the ground, and also the directions of the slopes remained the same throughout all tests.

Wind Velocity

A three cup totalizing type anemometer with dial for registering wind movement was mounted 4 feet above the ground. The anemometer, placed near the 10 percent slope, is shown in Figure 21.

Source of Water

A steel tank placed near the test field was used as a water sump. (Figure 22) A hose supplied water to the tank from a nearby tap. A jet pump supported by planks on top of the tank supplied water at a pressure of approximately

Fig. 21. Three cup totalizing type anemometer.

Fig. 22. Steel storage tank used as water sump, electric motor driven jet pump, and the pressure drum.

Fig. 23. Hose connections to the sprinkler, pressure gauge and slope screens.

70 psi. The discharge pipe from the pump was connected to the top of the pressure regulator drum, by means of a G. I. pipe, globe valve, and a piece of hose. An outlet pipe at the base of the drum was connected to a 150 foot length of one-inch diameter hose. The hose in turn was connected to the sprinkler. A globe valve was used to control the flow to the sprinkler. The sprinkler, hose pipe connections, pressure gauges and the screens, are shown in Figure 23. The sprinkler was allowed to water a full circle. A glass jar or an empty bucket was placed over the sprinkler at the end of a test run.

Discussion

To start the tests, the pressure was first adjusted on the gauge and when it became constant at the desired pressure, the cover over the sprinkler was removed. The starting time of the test was noted and also the initial reading of the anemometer. After one hour, the sprinkler was again covered to end the test, and the anemometer reading was again recorded. The subtraction of these two hourly anemometer readings gave the total miles of wind passing the anemometer. Sprinkler A was used with 11/64 inch diameter nozzle and was operated at each test pressure for one hour. The quantity of water collected in each can on each slope was individually measured in the graduated volumetric cylinder, and the average

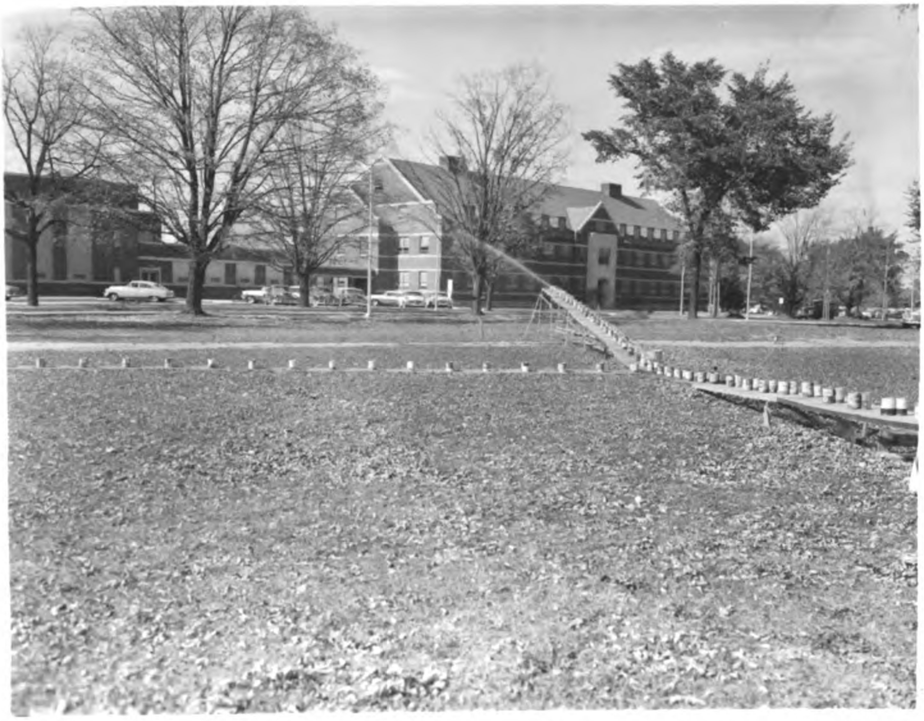


Fig. 24. View of the three slopes being sprinkled during a test.

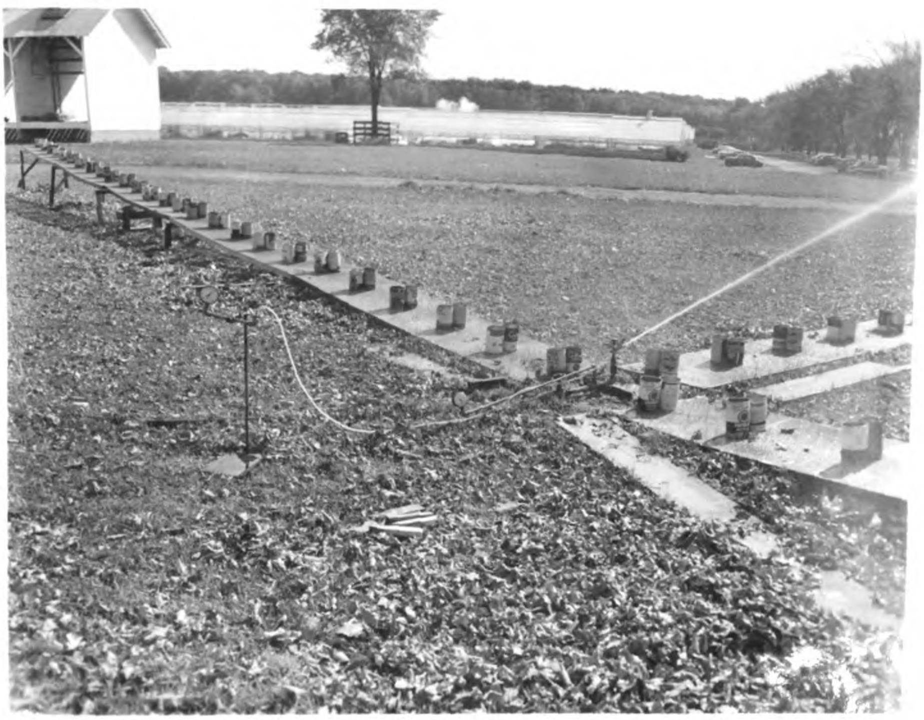


Fig. 25. Jet of water falling upon the test area using sprinkler B.

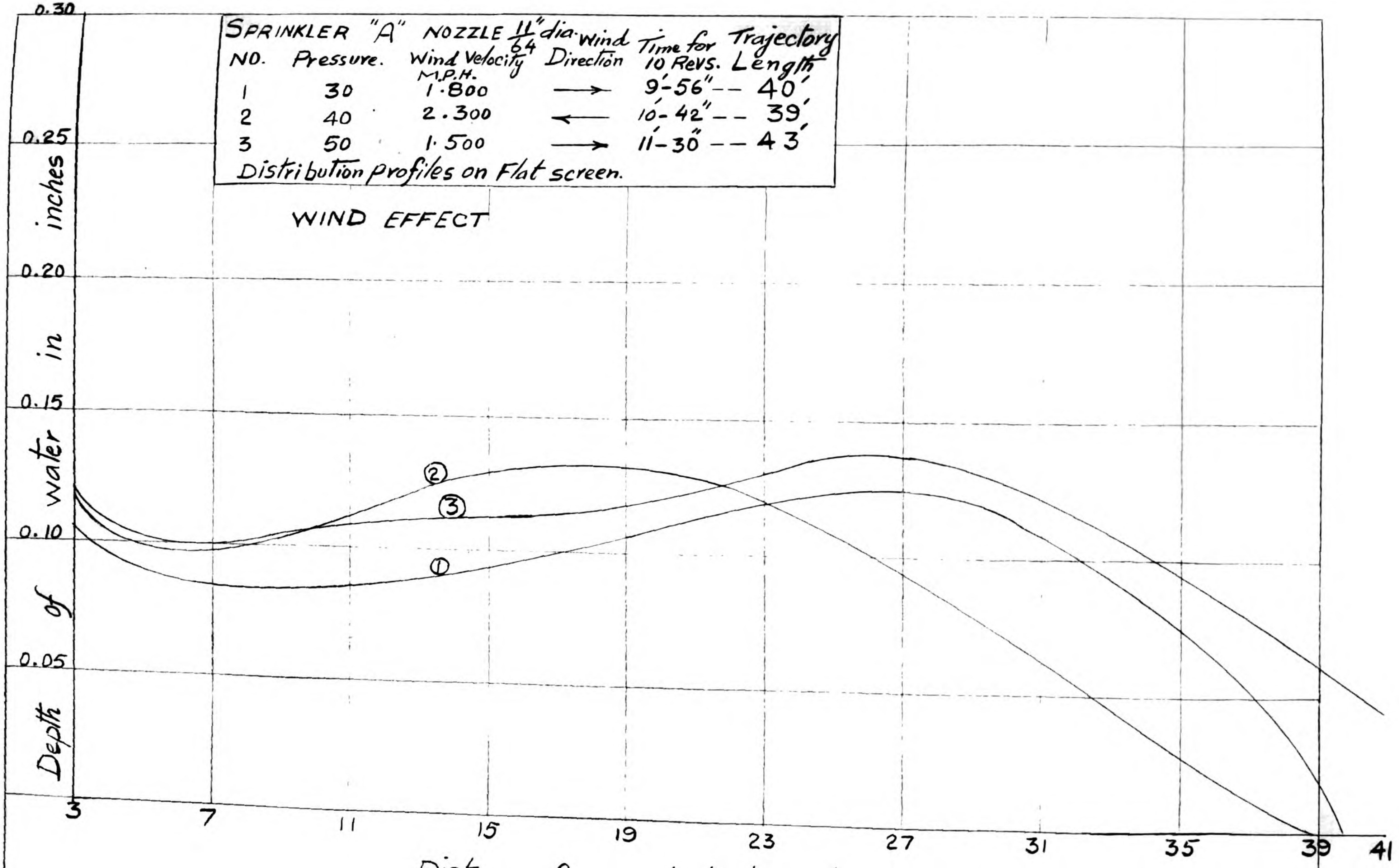
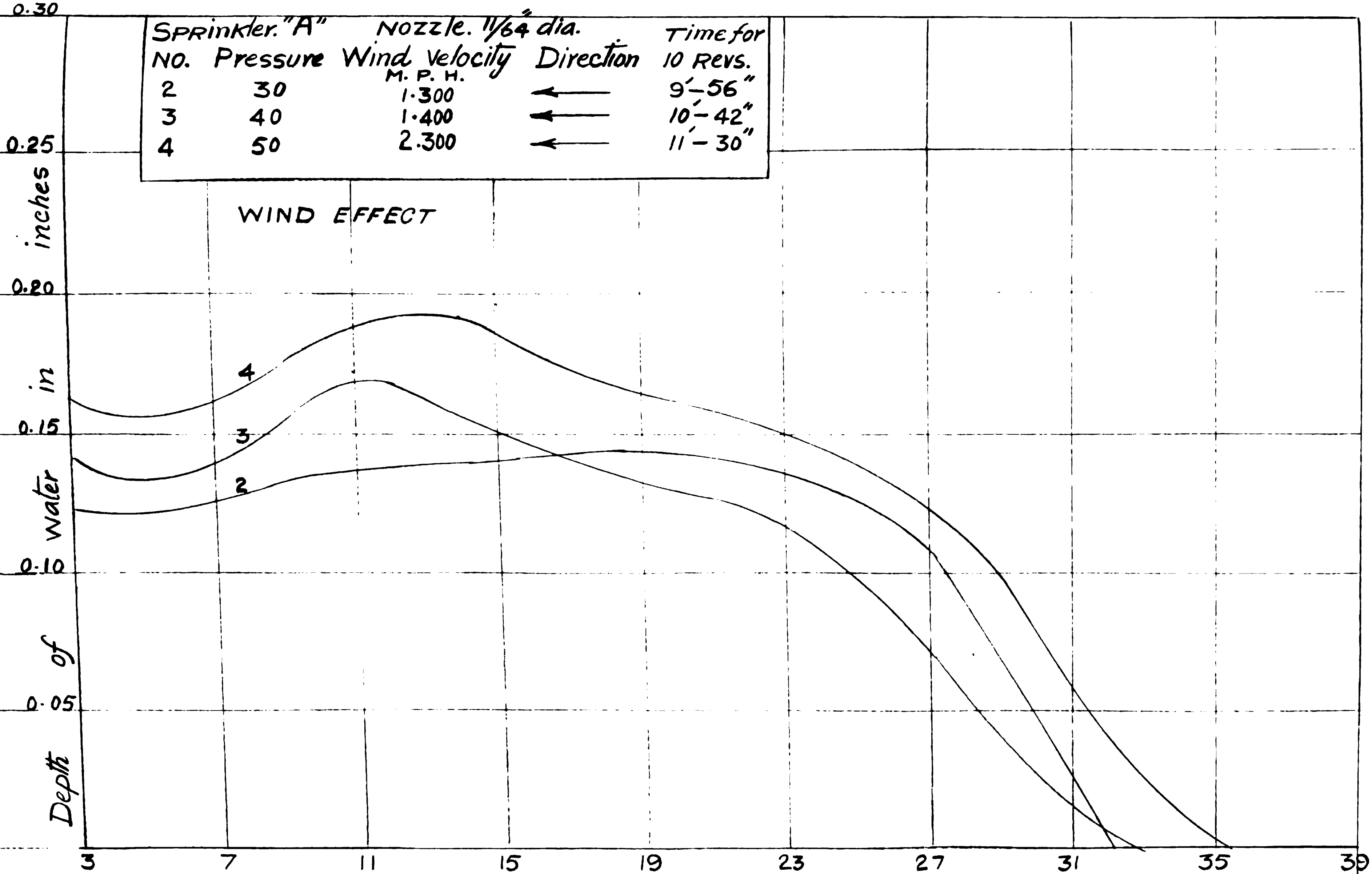


FIG. 26 Distribution Profiles on flat, using 11/64" dia. nozzle on various pressures under wind condition.

Sprinkler "A" Nozzle [illegible] dia. Time for

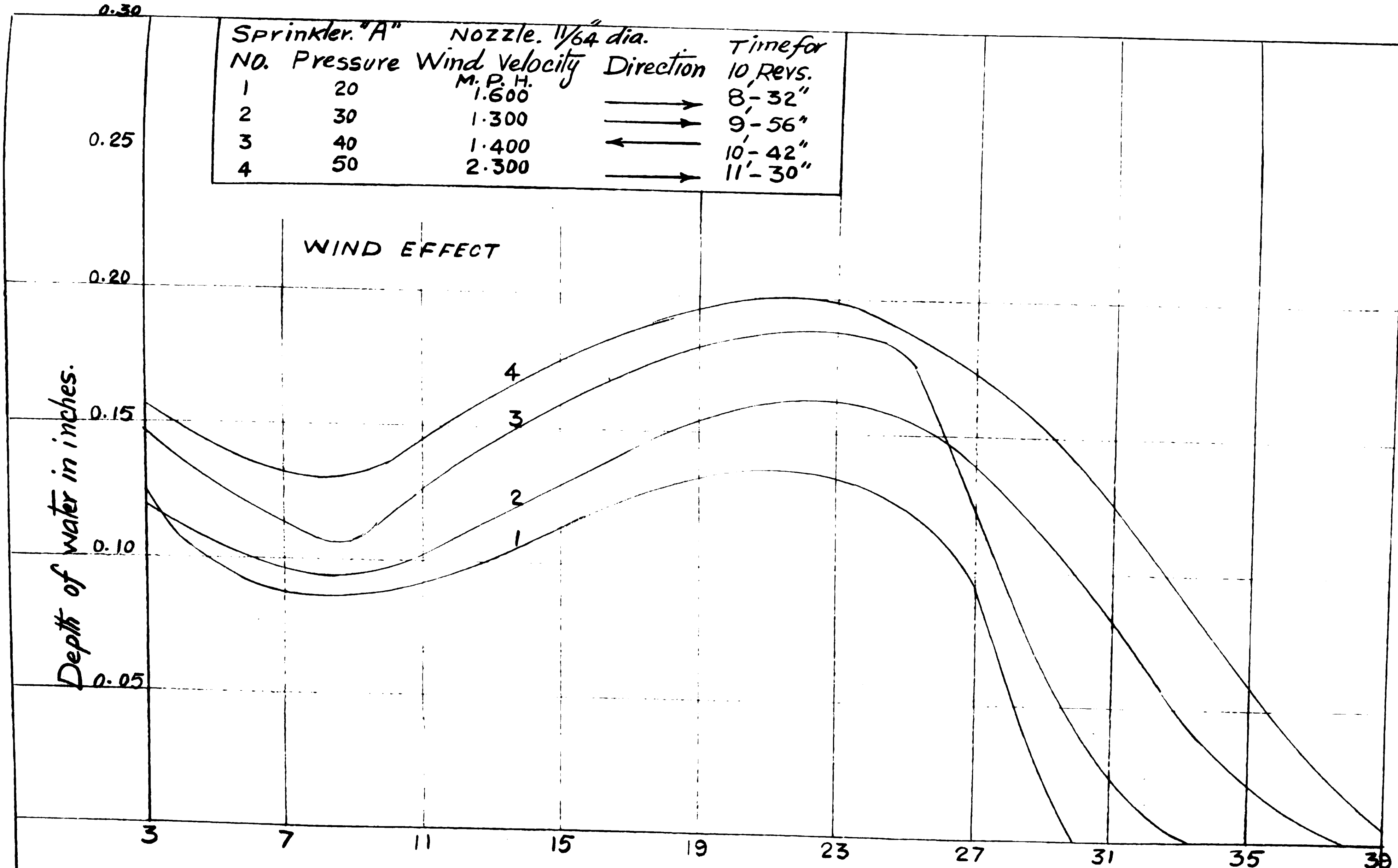
No. Pressure Wind Velocity Direction [illegible]



Distance from sprinkler in feet.

FIG. 27 Distribution profiles on 5% slope using 11/64" dia. nozzle on various pressures under wind condition.

No. Pressure Wind velocity Direction



Distance from sprinkler in feet.

FIG. 28 Distribution profiles on 10% slope using 11/64" dia. nozzle on various pressures under wind conditions.

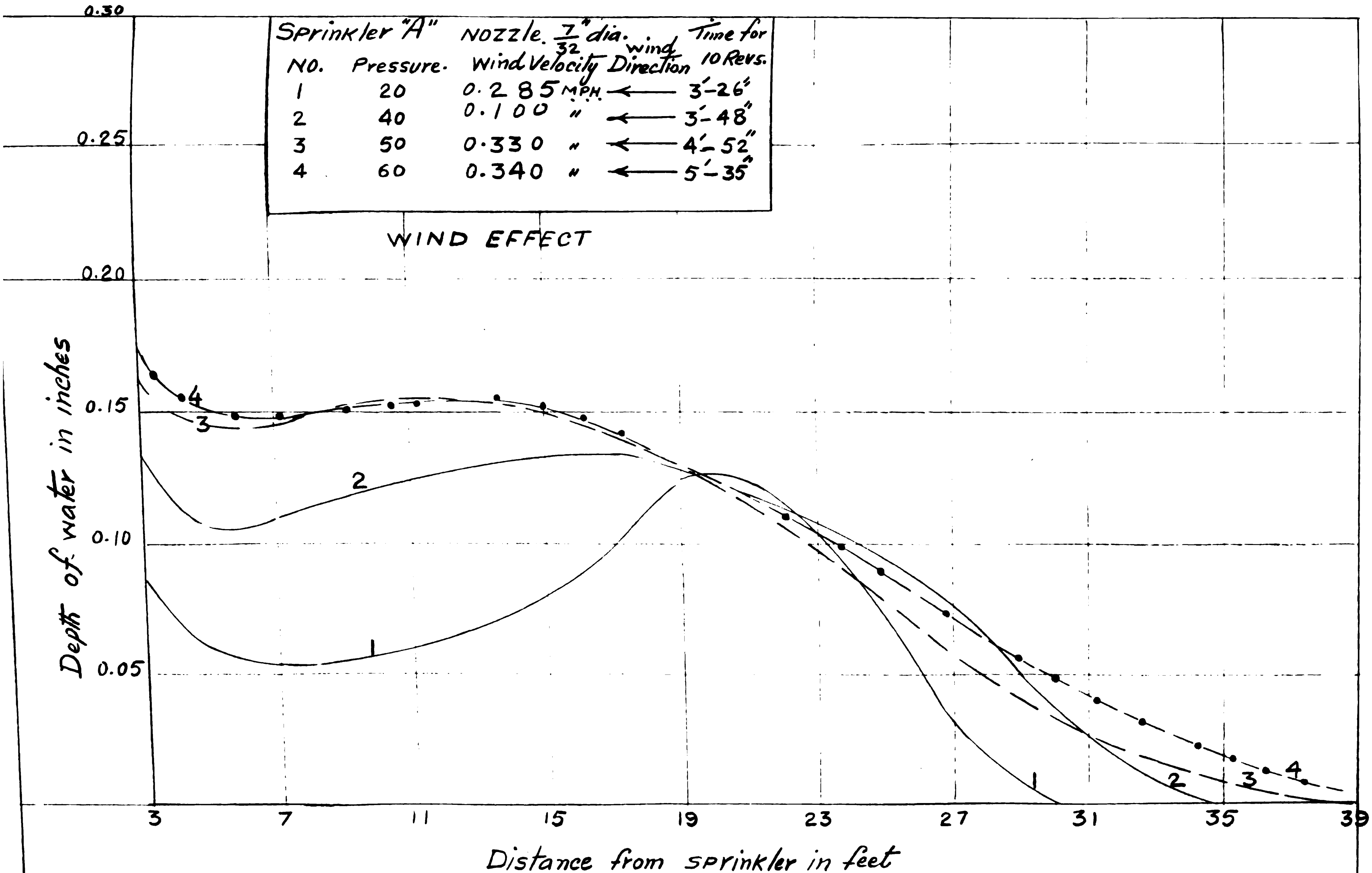


FIG. 29 Distribution profiles on flat, using $\frac{7}{32}$" dia. nozzle on Various pressures under Wind Condition.

Sprinkler No	"A" Pressure	Nozzle Wind Velocity	Wind Direction	Time for 10 Revs

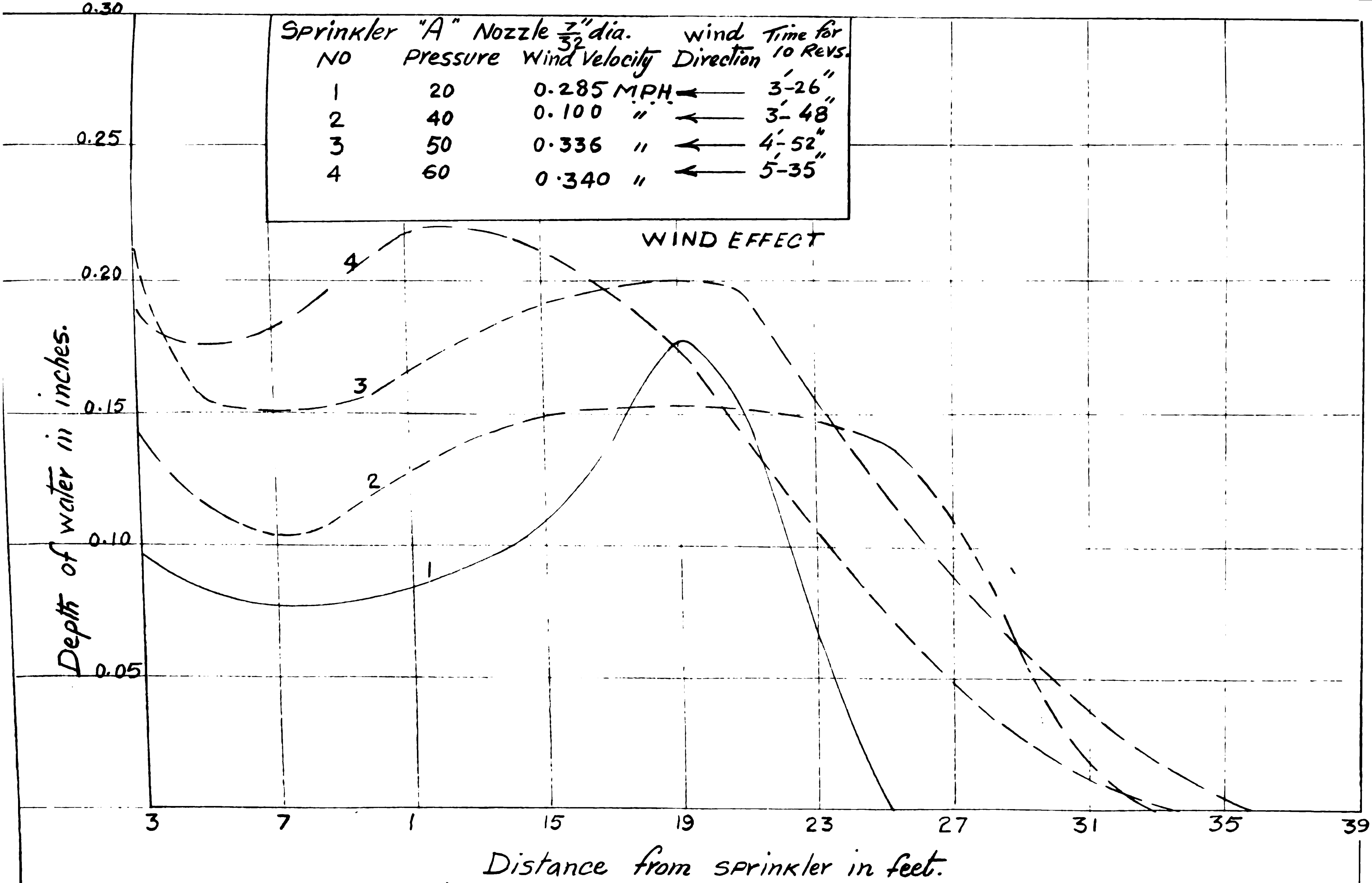


FIG. 30 Distribution profiles on 5% slope, using 7/32" dia. nozzle on Various pressures under wind Conditions

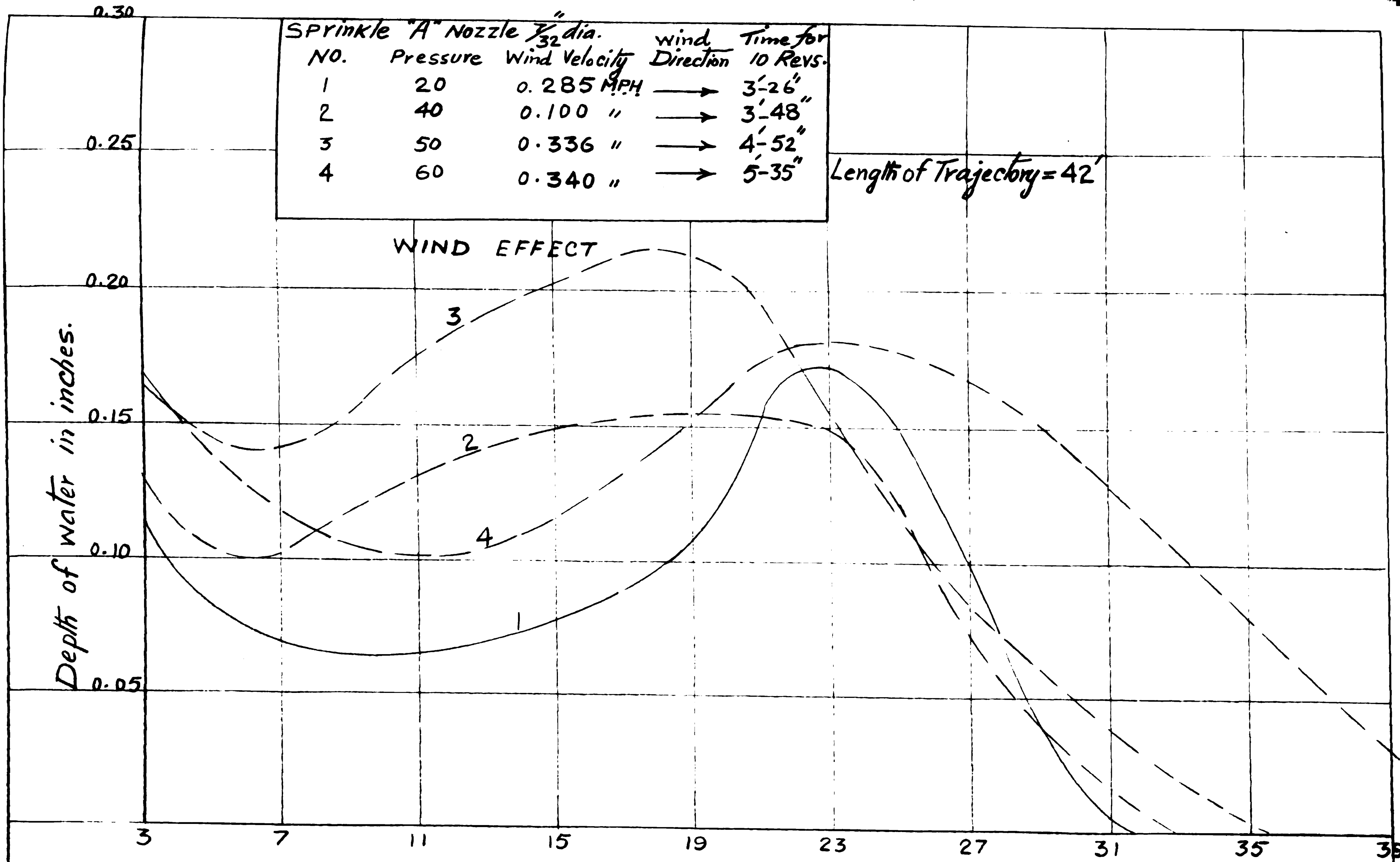
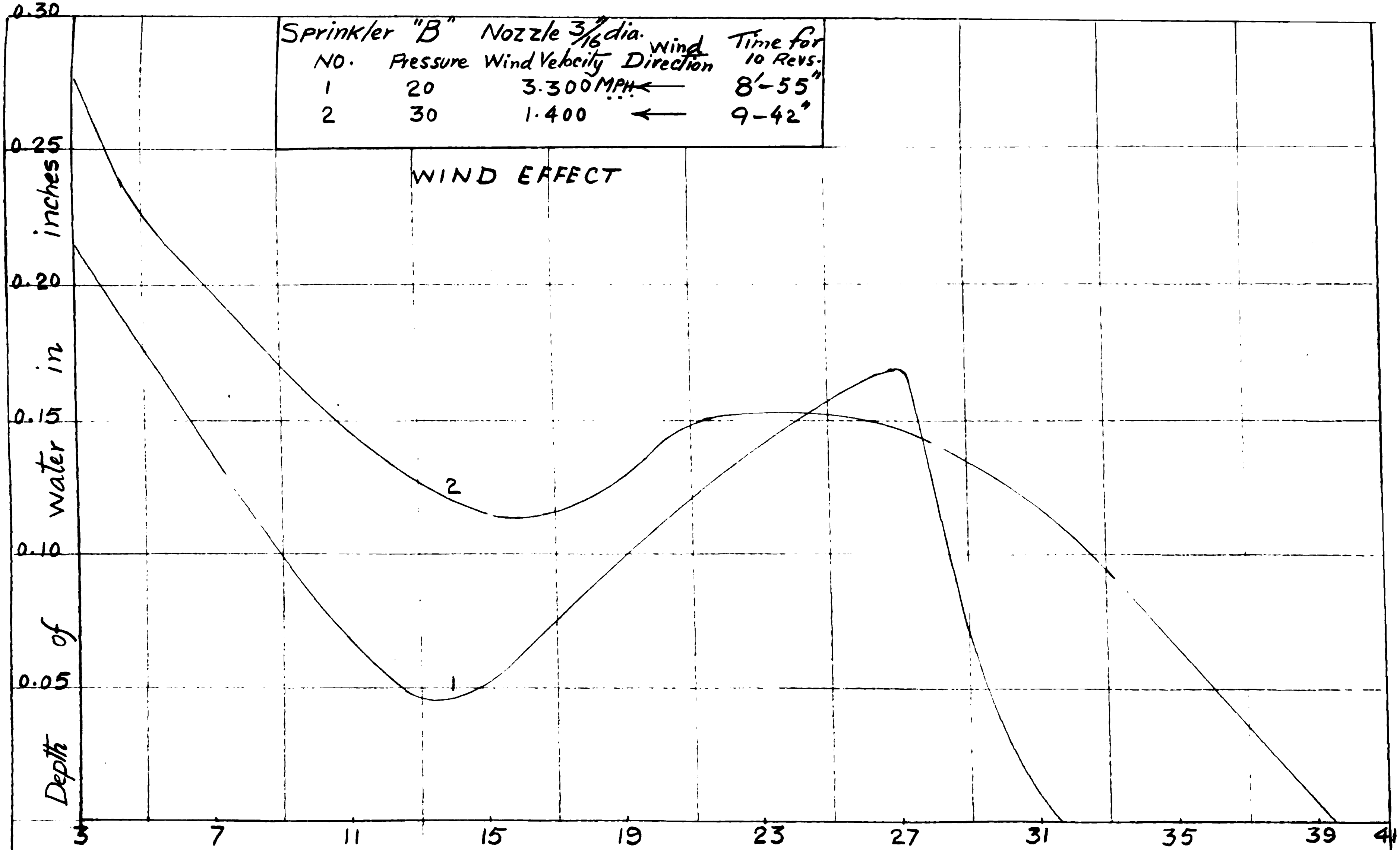


FIG. 31 Distribution profiles on 10% slope, using 7/32" dia. nozzle on various pressures under wind conditions.



Distance from sprinkler in feet.

FIG. 32 Distribution profiles on 5% slope using sprinkler "B" and 3/16" dia. nozzle.

quantity of each can location was converted into inches of water per hour. The sprinkler is shown in operation with the test slopes in Figure 25.

The distribution profiles for 11/64 inch diameter nozzle on 30, 40 and 50 psi are plotted for the flat, 5 percent slope and 10 percent slope. (Figures 26, 27 and 28) The wind velocity has a very great effect upon the distribution profile. If the direction of the wind is roughly the same as the direction of the flow of the jet, then the trajectory length increases. In Figure 12 the length of the trajectory was 39 feet for the same 11/64 inch diameter nozzle at 30 psi under no wind condition, but in Figure 26, the length of the trajectory is increased to 40 feet. The depth of water was reduced, because the same quantity of water was sprinkled on a longer radius, and moreover the wind scatters the droplets into the air that move in the direction of the wind. The distribution profiles for different pressures may be somewhat similar to each other, if the wind blows at a uniform velocity in the same direction.

The tests were repeated using a 7/32 inch diameter nozzle on 20, 40, 50, and 60 psi pressures. (Figures 29, 30 and 31) The distribution profiles on the flat (Figure 29) are mostly similar on different pressures, except the profile at 20 psi pressure, a pronounced peak developed at about 20 feet from the sprinkler. Referring to the test carried out

Sprinkler "B" Nozzle dia. 3/16" Time for
Pressure. 20 psi. 10 hrs.

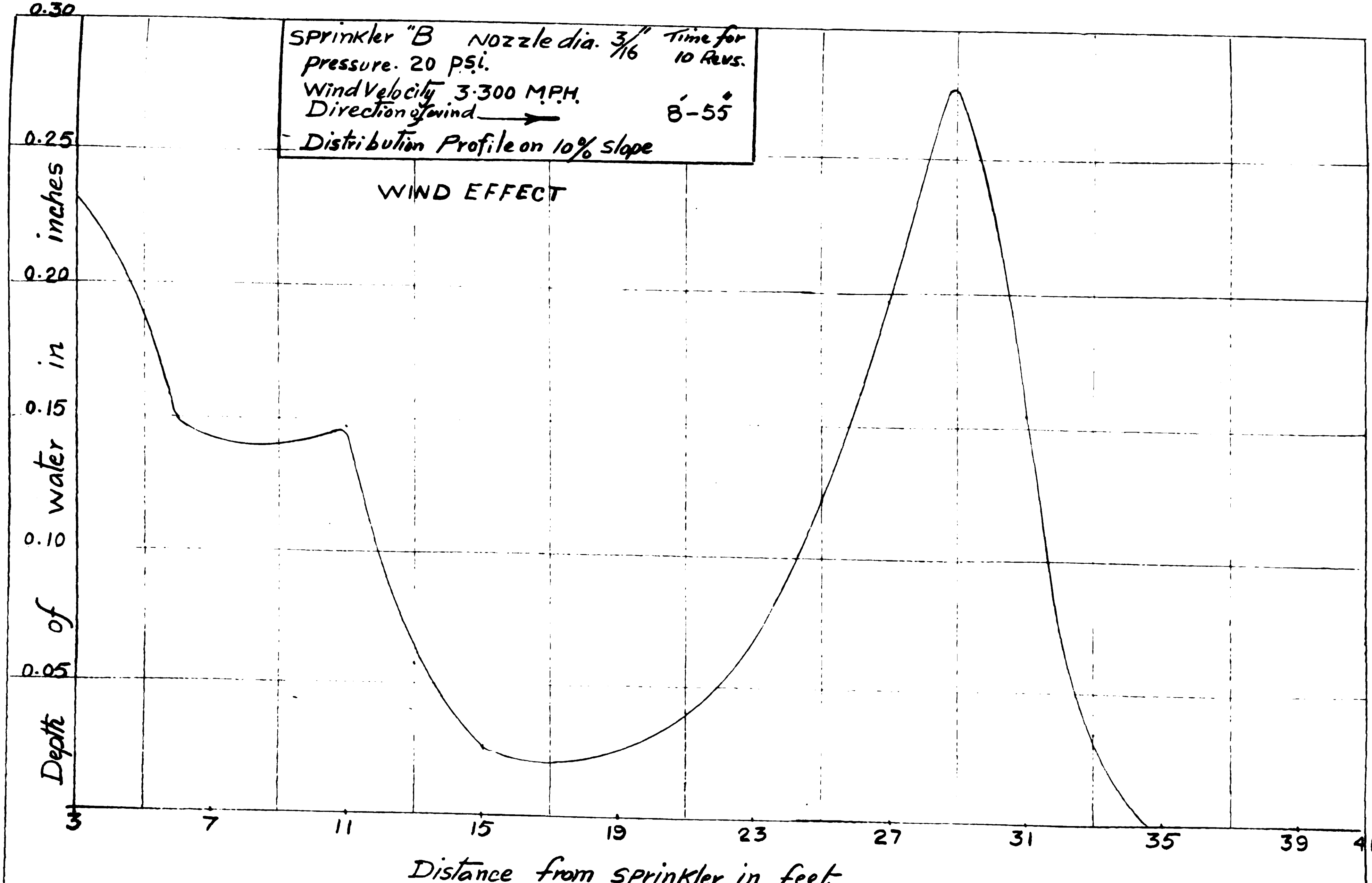


FIG. 33 Distribution profiles on 10% slope using sprinkler "B" and 3/16" dia. nozzle.

in the laboratory (Figure 8), the distribution profile of 20 psi pressure, shows a peak at about 29 feet from the sprinkler, which is shifted inward to 20 feet by wind effect. (Figure 29) The distribution profiles at 20 psi on 5 percent and 10 percent slopes also show a pronounced peak at 19 and 23 feet respectively (Figures 30, 31). As the pressure increases, the length of the trajectory normally increases, but the direction and velocity of the wind will cause the trajectory to be reduced or pushed forward. When the trajectory distance is reduced, the rate of precipitation will be higher than when the trajectory distance is increased.

Tests were carried out on sprinkler B using a 3/16 inch diameter nozzle at 20 and 30 psi pressure. The distribution profiles on 5 percent and 10 percent slopes are shown in Figures 32 and 33. The profile at 20 psi shows a peak at 27 feet in Figure 32 and at 29 feet in Figure 33. This pattern is similar to the profiles obtained with sprinkler A at the same pressures.

SUMMARY

A study was undertaken in which the distribution profiles from two medium pressure sprinklers were evaluated under conditions of several nozzle diameters, pressures, combinations, on flat, 5 percent, 10 percent slopes, in the laboratory and under outdoor conditions.

These tests indicate that when the sprinkler operates under no wind conditions, the trajectory is fairly long, and it increases in length when the pressure is increased. The distribution of water near the sprinkler is always very high, because of the obstruction of the jet by the oscillating arm used to rotate the sprinkler. Operating the sprinkler at optimum pressures, resulted in a desirable distribution of water. Increasing the size of the orifice of a sprinkler nozzle, resulted in a better distribution of water. Increasing the angle of inclination of a sprinkler nozzle from the horizontal, resulted in an improved distribution of water. For low pressures of 20 psi the distribution profiles end abruptly after coming to a pronounced peak, whereas with medium pressures, the trajectory covers a longer distance and the secondary peak is minimized.

If the sprinkler is kept on a slope, and the sprinkler riser pipe is at a right angle to it, the distribution profile

will be altered on the up-slope. The length of the trajectory will be reduced thereby increasing the rate of precipitation in that area.

Having determined the precipitation profiles on the flat, 5 percent and 10 percent slopes for different pressures, the precipitation profiles for the in-between slopes may be interpolated. This will give the amount of precipitation along a radius and the length of the trajectory for a particular pressure, nozzle diameter, and slope.

The wind materially affects the distribution profiles. When the jet of water moves along the direction of the wind, it is pushed forward distributing water over a longer radius. When the jet of water moves against the direction of the wind, it is pused back resulting in an increased precipitation rate over a short radius. The distribution profiles become very much distorted if the wind velocity is high.

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Date Due

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