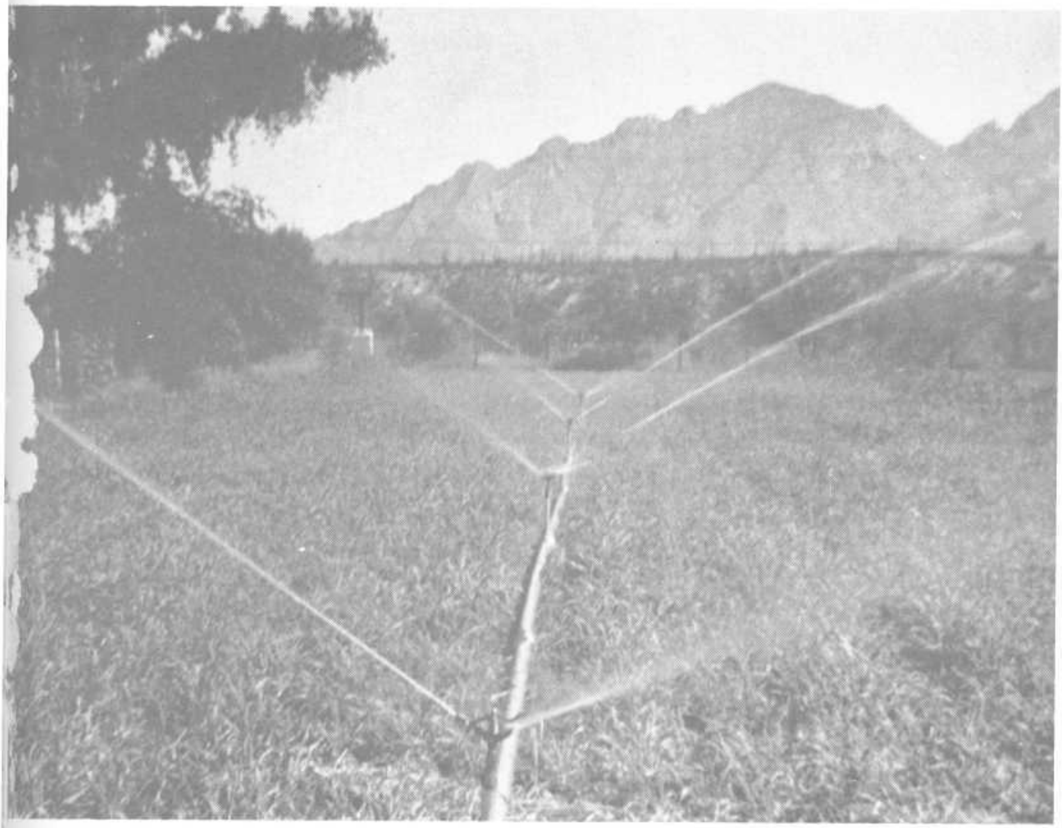
Sprinkler Irrigation



BULLETIN A-24

Agricultural Experiment Station and Cooperative Extension Service

The University of Arizona

Contents

This publication is a reprint (with slight revision) of former Bulletin 250 with the same title.

Trade names used in this bulletin are for identification purposes only and do not endorse products named nor imply criticism of similar ones not mentioned.

Issued in furtherance of cooperative extension work in agriculture and home economics, acts of May 8 and June 30, 1914, in cooperation with the U. S. Department of Agriculture. George E. Hull, Director of Extension Service, The University of Arizona College of Agriculture, Tucson, Arizona.

3M—January 1963—Bulletin A-24

Sprinkler Irrigation

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Introduction

Sprinkling has been used as a method of irrigation for almost fifty years in some parts of the United States, and the last few years has become popular as a means of applying water to field crops. The first sprinkler systems were used in nurseries and on vegetable crops in the eastern states to supplement rainfall. Although few sprinkler systems were in operation in the West before 1930, there were some growers in California irrigating by sprinkling in citrus orchards as early as 1920.

Practically all installations made prior to 1930 were permanent systems. Portable sprinkler systems came into use with the introduction of quick couplings and lightweight steel pipe about 1930. At the end of World War II, aluminum tubing became available and has rapidly replaced steel as portable pipe because of its light weight. The development and perfection of the quick-coupler has also encouraged the use of sprinkler irrigation.

Advantages of Sprinkling

Some of the advantages claimed for sprinkler irrigation may have little importance in certain areas and yet be of major importance in others. There may even be considerable variation in the merits of this method of applying water to crops within a certain locality.

A grower should carefully weigh the advantages that apply to his area or to his particular farm. The principal advantages are summarized in the following paragraphs.

1. Land with irregular topography can be sprinkler irrigated with a minimum of leveling and disturbance of topsoil. Extensive leveling often exposes subsoils unsuitable for crop production.

2. Fields can be irrigated without excessive losses from deep percolation or surface runoff and conveyance losses may be eliminated.

3. Frequent light applications can be made on soils of low water-holding capacity, shallow depth, or for the irrigation of shallow-rooted crops.

4. A properly designed sprinkler system gives more uniform distribution of water than most surface methods of irrigation.

5. By adequate control of soil-moisture conditions, uniform and complete seed germination and crop stands may be obtained.

6. The rate of application with sprinkler irrigation can be selected so that little or no loss by soil erosion occurs on sloping lands which are easily eroded by surface irrigation.

7. Farm machines are easier to operate in fields without ditches or borders.

8. The area occupied by ditches and borders under surface methods of irrigation is available for crop production and problems of ditch maintenance are eliminated.

9. Drainage problems due to overirrigation or to seepage losses from field ditches may be avoided.

10. Liquid fertilizers can be applied through the sprinkler system.

11. A more effective use can be made of a small, continuous stream of water with a sprinkler system, thus permitting the irrigation of a larger acreage per unit of flow.

Disadvantages of Sprinkling

There are some disadvantages to sprinkler irrigation which are peculiar to this method and they should be considered and compared with its advantages. Problems arising from this method of irrigation may prove costly unless a thorough investigation justifies its installation.

The following disadvantages merit consideration:

1. The initial cost of a sprinkler installation may be high compared with the initial cost of leveling new land which requires little preparation for irrigation by surface methods. On lands already prepared for surface irrigation, a sprinkler system represents an additional capital investment.

2. Operating costs are usually increased by the necessity of providing water under a pressure of approximately 40 pounds per square inch (psi) at the sprinklers or the equivalent of about 92 feet of additional pump lift.

3. Labor costs of water application are in some instances higher for sprinkler irrigation than for surface methods. This is particularly true in Arizona where many delivery heads are between 5 and 15 cubic feet per second and may require only one irrigator.

4. Usually the most economical size of stream for sprinkler irrigation is the smallest continuous stream which will satisfy the crop requirements during the season of peak demand. Continuous flow delivery and small irrigation heads are not available from most irrigation water companies or districts in Arizona.

5. Engineering knowledge and experience in the design and planning of a sprinkler system is essential if the system is to operate effectively and with lowest possible costs.

6. Moving lateral pipe lines in soft and sticky soils or in tall crops, such as cotton, grain or maize, is a difficult and disagreeable task. It may present a serious labor problem.

7. Regardless of how carefully a sprinkler system is designed, some mechanical difficulties may be expected. Sprinklers may fail to rotate, nozzles may become plugged, or sand or gravel may lodge at the couplings causing excess leakage. The pump with its engine or electric-motor drive will require attention.

8. Wind creates one of the major problems confronting sprinkler irrigation. High-velocity winds may prevent irrigation at a critical time, result in uneven distribution of water, and cause excessive water losses by evaporation and drifting of the spray.

Types of Sprinkler Systems

Sprinkler systems are classified in three general groups according to method by which the water is distributed: nozzle line, perforated pipe, and rotating-sprinkler systems. A brief discussion is presented in the following pages on nozzle-line systems and perforated-pipe systems.

Rotating-sprinkler systems are discussed in more detail since these are more widely used than the other two methods of application. They are adapted to the irrigation of a greater variety of crops, a greater range in rate of application, and give a more uniform distribution pattern.

Initial installation costs of both rotating-sprinkler and perforated-pipe systems are lower than nozzle-line systems.

Nozzle-Line Systems

The first sprinkler systems consisted of a number of parallel lines of pipe supported above the ground and having small holes drilled in a single, straight row in each pipe. The pipes were turned by hand to obtain uniform coverage. Small nozzles placed 3, 4, or 5 feet apart in the lines are now substituted for the holes, and water-driven automatic oscillators are used to rotate lines up to 700 feet in length.

Photo No. 1 shows a nozzle-line system in use on the Soil Conservation Service Nursery plots near Tucson, Arizona. The nozzle lines, spaced 48 feet apart, are supported on posts with roller-wheel hangers at 12-foot intervals. This permanently installed nozzle-line system

Photo No. 1—Oscillating nozzle line in permanent sprinkler system located at USDA Plant Materials Center near Tucson, Arizona.

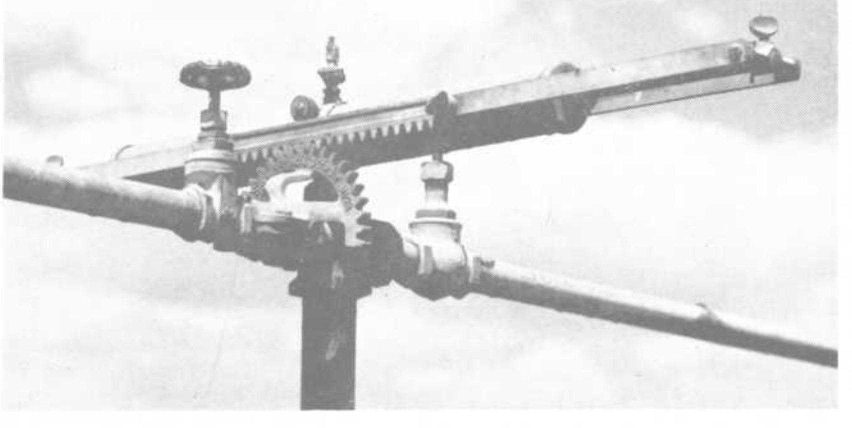

Photo No. 2—Automatic oscillator, actuated by water pressure, which turns the pipe through an arc from 90 to 120 degrees.

operates on pressures of 35 to 40 pounds per square inch (psi), uses about 8 gallons of water per minute (gpm) for each 100 feet of line and can apply an inch of water in 8 hours. The automatic oscillator used on this system is shown in Photo No. 2.

A 100-foot line having thirty-three nozzles of approximately ¼ gallon per minute discharge per nozzle and with nozzles spaced 3 feet apart will require only ¾-inch pipe. A 300-foot line containing 100 nozzles will require about 110 feet of 1¼-inch pipe, 100 feet of 1-inch pipe, and 90 feet of ¾-inch pipe.

Portable-nozzle-line systems with automatic oscillators are supported on short posts in some instances. Nozzles are usually spaced 5 feet apart in the portable lines and discharge from ¼ to 3 gallons per minute per nozzle. Pressures vary from 15 to 50 pounds per square inch. The most satisfactory operating pressure is around 35 pounds per square inch.

Pipe size required will vary with the length of the line to be used and the discharge of the nozzles. Dealers selling this equipment should be able to recommend proper pipe sizes or obtain design information from manufacturers.

A permanent nozzle-line system requires little labor to operate but is costly to install and the supporting posts are an obstruction in the field. A portable-nozzle-line system is much lower in cost but is not well adapted to rapid moving of laterals.

Perforated-Pipe Systems

Perforated-pipe laterals (Photo No. 3) operating under pressures from 2 to 20 pounds per square inch can be used on pastures and low-growing crops. Pressures of 4 to 15 pounds per square inch are used in a majority of the installations of this type, with spreads of 20 to 50 feet obtainable within this pressure range. Perforated pipe is now available with perforations that will apply up to 2 inches and as low as ½-inch of water per hour.

The cost of a perforated-pipe system is relatively low, but the rapid application of water generally limits its use to porous soils. Rapid application requires frequent moves since most porous soils have a low water-holding capacity.

The perforated pipe is equipped with quick-couplings and comes in 10- to 20-foot lengths. Several

Photo No. 3—Perforated-pipe lateral used on experimental plots near Yuma, Arizona.

rows of small holes spaced 2 to 3 feet apart in each row are placed in the upper part of the pipe. Since the holes are small a good screening device is essential to remove floating material in the water that may cause clogging. Sand will ordinarily settle at the bottom of the pipe and can be removed by an occasional flushing of the line.

The low pressures required to operate a perforated-pipe system sometimes enable the utilization of natural fall between the water source and the land to be irrigated. A foot of difference in elevation between the water surface and the ground surface is equivalent to 0.434 pounds per square-inch pressure. Thus, if a water supply is 20 feet above the ground to be irrigated, a pressure of 8.68 pounds per square inch is available.

Pipe sizes required will vary from 3 inches on short laterals to 6 inches in diameter on the longer ones. Friction loss in the pipe should not exceed 20 percent of the pressure at the head of the lateral and will vary with the volume of water, length of lateral, and size of the pipe. Engineers employed by manufacturers selling this equipment can be consulted for information regarding the proper pipe size to use.

Rotating-Sprinkler Systems

Nearly all rotating-sprinkler systems being sold today are portable or semiportable. In the portable system the pump, main line, and laterals can be moved from field to field. In the semiportable system, the pump and main lines are installed permanently and only the lateral lines are moved. Permanent systems of this type are designed with underground main and lateral pipe lines. The laterals are equipped with stationary risers to which large capacity sprinklers are attached or from which small hose-connected sprinklers are operated.

Photo No. 4 shows typical quick-couplers used for portable lateral pipe lines. Couplings should be lightweight, leakproof at operating pressures, and easily connected and disconnected. It should not be necessary for the operator to walk to the coupler to connect or disconnect it.

Permanent main lines are made of thin-wall steel or aluminum pipe; however, steel should be used if the line is to be buried. Double-dipped, asphalt-treated-steel pipe is generally used since it will outlast untreated pipe.

Sections of steel pipe are usually connected with welded joints which should be retreated after welding. Dayton- or Dresser-type couplings are used where semi-flexible connections are required, such as pump connections. Many sprinkler manufacturers make lower-cost special main-line couplings for use with aluminum pipe, but these do not have the riser outlets and are not designed for quick coupling and uncoupling.

Valve-opening elbows similar to those pictured in Photo No. 5 are usually used on main lines to enable the operator to shut off the flow in a lateral and move it to the next position while other laterals remain in operation. Photo No. 6 shows this type of valve being used with an aluminum main line and aluminum laterals. The valves are located 60 feet apart on the main line and the sprinklers are spaced 40 feet apart in the lateral.

Sometimes laterals are connected to the main line by using only tees or elbows, thus saving the expense of valves. The disadvantage of having to shut off the pump when the laterals are moved is a consideration that should not be overlooked.

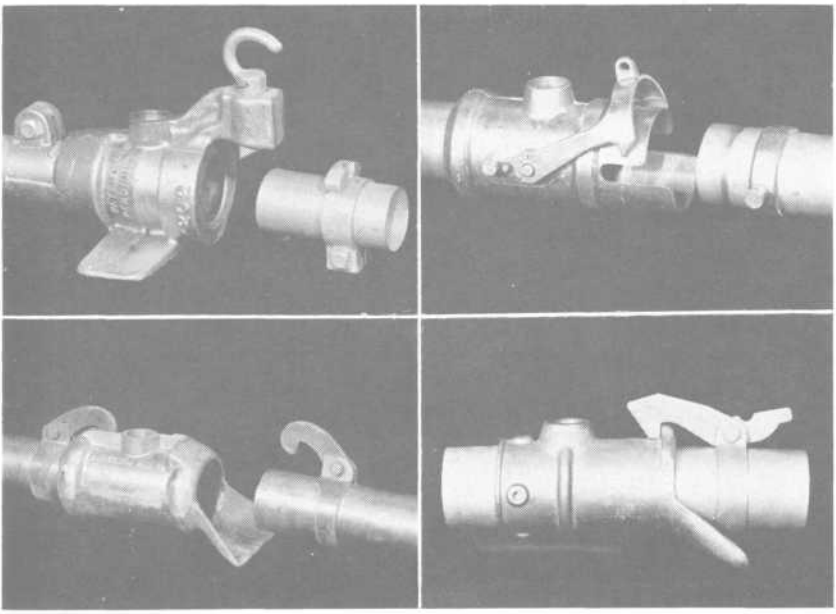

Photo No. 4—Typical quick-couplings of cast aluminum, with the threaded riser outlets, used for connecting portable aluminum pipe.

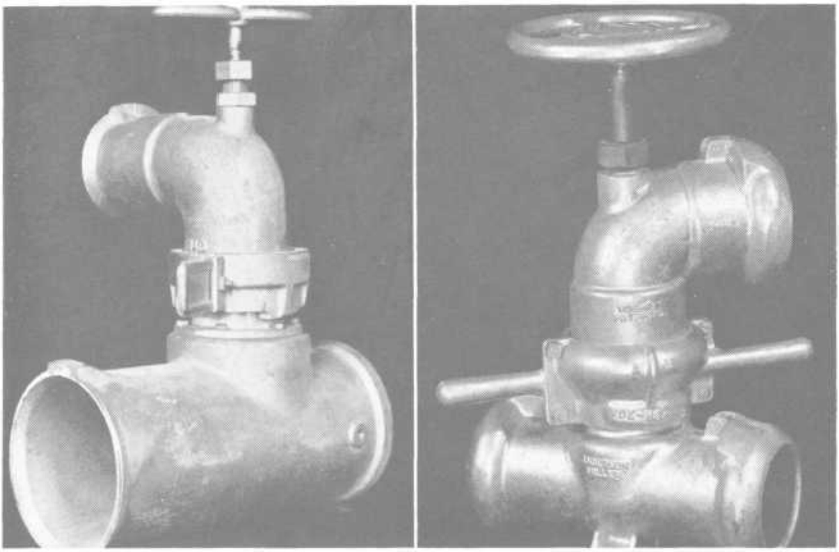

Photo No. 5—Quick-coupling, main line T-valves with portable valve-opening elbows in place. The valve-opening elbows are moved with the lateral.

Photo No. 6—Irrigation of permanent pasture in Williamson Valley near Prescott, Arizona. T-valves are placed in the 6-inch aluminum main line at 60-foot intervals. Rotating sprinklers are spaced 40 feet apart on aluminum laterals.

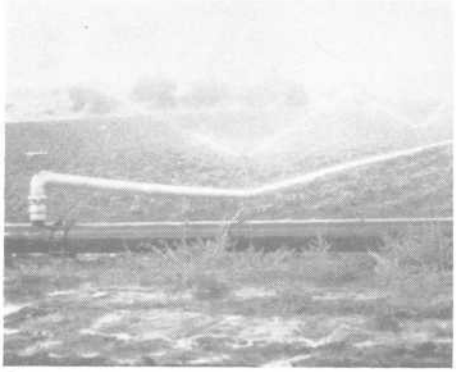

Photo No. 7 — Aluminum laterals with a permanent asphalt-treated-steel main line. Threaded valves are attached to steel risers welded to the main line.

Steel risers threaded for aluminum valves are welded into the steel pipe at proper intervals for laterals, and the valves are operated with a valve-opening elbow. The asphalt-treated steel main line shown in Photo No. 7 is connected with Dresser-type couplings and has valves placed 60 feet apart.

Double-nozzle sprinklers of the type shown in Photo No. 8, commonly used in the irrigation of field crops, are equipped with a range nozzle for distance and a spreader nozzle for the inner portion of the wetted area. Nozzles are removable and their sizes are designated by the diameter of the nozzle opening. The nozzles in a

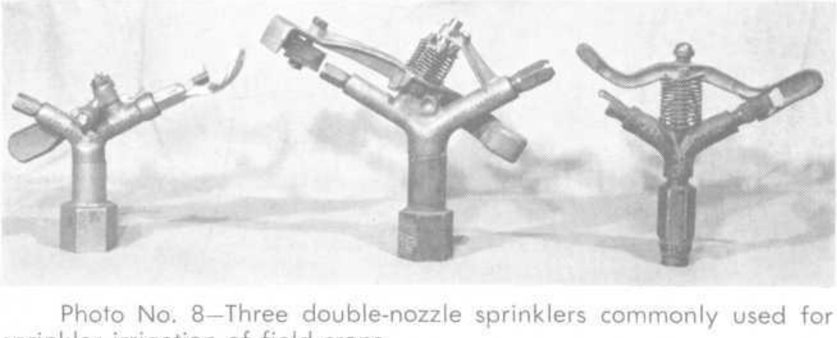

Photo No. 8—Three double-nozzle sprinklers commonly used for sprinkler irrigation of field crops.

TABLE 1.—Computed discharge* from various sizes of nozzles at different pressures and corresponding diameters of wetted areas with a 40-degree sprinkler head.

Pressure in	Diameter of Nozzles in Inches																	
lb. per	3/32		1/8		5/32		11/64		3/16		13/64		7/32		1/4		9/32	
sq. inch	Dia†	gpm‡	Dia	gpm	Dia	gpm	Dia	gpm	Dia	gpm	Dia	gpm	Dia	gpm	Dia	gpm	Dia	gpm
	ft.		ft.		ft.		ft.		ft.		ft.		ft.		ft.		ft.	
25	—	1.22	—	2.17	82	3.40	83	4.10	85	4.88	86	5.71	88	6.67	91	8.70	95	11.0
30	—	1.34	—	2.38	85	3.72	88	4.50	91	5.35	94	6.28	96	7.31	100	9.52	104	12.1
35	—	1.45	—	2.57	87	4.02	90	4.86	94	5.78	98	6.78	101	7.91	106	10.3	110	13.0
40	—	1.55	—	2.75	88	4.30	92	5.20	96	6.18	101	7.26	105	8.45	110	11.0	115	13.9
45	—	1.64	—	2.92	89	4.56	93	5.51	98	6.56	103	7.70	108	8.92	114	11.7	119	14.8
50	—	1.73	—	3.07	90	4.80	95	5.80	100	6.90	105	8.10	110	9.38	118	12.3	123	15.5
55	—	1.81	—	3.22	91	5.03	96	6.08	101	7.22	107	8.48	112	9.83	121	13.1	126	16.3
60	—	1.90	—	3.37	92	5.25	97	6.37	102	7.56	108	8.88	113	10.3	123	13.5	127	17.0

*Computed from formula $Q = CA\sqrt{2gh}$, with coefficient of discharge, $C = 0.93$.

†Dia. = Diameter of wetted area, from Sprinkler Irrigation Handbook, Rain Bird Mfg. Corp., Glendora, California.

‡gpm = gallons per minute.

sprinkler with a ¼-inch range nozzle and a 3/16-inch spreader nozzle are described as 1/4 x 3/16.

The discharge from a nozzle varies with the operating pressure at the nozzle and the area of the nozzle opening. Thus, a wide range in discharge may be obtained by a variation in operating pressure combined with different size nozzles. (See Table 1, page 11.)

The discharge will vary slightly with the design of the nozzle. The coefficient of discharge used for computing discharges in Table 1 was 0.93 which is an average value for sprinkler nozzles. To find the discharge for double-nozzle sprinkler heads add the discharges of the individual nozzle in Table 1.

The diameter of the circular area wetted by a rotating sprinkler varies with the pressure at the nozzle, the discharge angle of the nozzle and the diameter of the nozzle. For example, the diameter of the pattern of a 40-degree discharge-angle sprinkler using a 3/16-inch range nozzle at a pressure of 25 pounds per square inch is 85 feet, at 40 pounds per square inch it is 96 feet and at 60 pounds per square inch, 102 feet. The stream from the smaller diameter nozzles is broken up into finer droplets and is more affected by the resistance of the air, thus the pattern diameter is less for the same operating pressures.

The effect of different pressures and various nozzle combinations on the diameter of the wetted area is shown in Table 1.

In order to obtain uniform distribution of water, it is necessary to overlap adjacent sprinkler patterns, the maximum spacing between sprinklers should be no more than 60 percent of the wetted diameter. A common practice is to space the sprinklers on the laterals at intervals of 40 percent of the wetted diameter and make the distance between laterals not more than 60 percent. Where the prevailing wind is from one direction it is desirable to plan the sprinkler system layout so that the laterals are located at right angles to this direction.

Operating a sprinkler system with a pressure of 30 pounds per square inch at the nozzles is equivalent to lifting the water 69 feet above them. Doubling the operating pressure will approximately double the fuel consumption of the engine driving the pump or double the power requirements if an electric motor is used. High pressures will permit greater distances between laterals if wind interference is not a problem.

Some saving in labor for moving pipe will be obtained when lateral spacing is increased. Uniform water distribution is necessary for maximum crop production, and it is probable that for most areas pressures between 30 and 45 pounds per square inch and spacing 40 by 60 feet will give better results than higher pressures and wider spacings. Lower pressures and sprinkler spacings of 20 to 30 feet are often used in orchards.

Photo No. 9 shows single-nozzle, low-angle sprinklers that discharge from 1 to 9 gpm (gallons per minute) at pressures ranging from 5 to 50 psi (pounds per square inch). These sprinklers are popular for orchard use where low branches interfere with the spray from standard sprinklers. The diameter of the sprinkled area will vary from about 24 feet at a discharge of 1 gpm and a pressure of 5 psi to nearly 70 feet at a rate of discharge of 9 gpm and a pressure of 50 psi.

Pressures of 15 to 20 psi with sprinklers spaced 20 or 30 feet apart in the lateral are common for orchard sprinkling. Since standard aluminum pipe is only available in 20, 30 and 40-foot

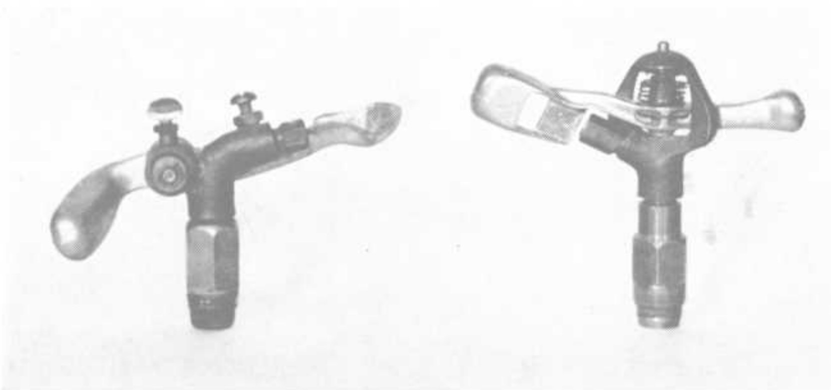

Photo No. 9—Low-angle, single-nozzle, under-tree sprinklers used in sprinkler irrigation of orchards.

lengths, it is not always possible to have a sprinkler operating in the center of the squares formed by four trees. Custom-made aluminum pipe of any specified length may be ordered at a slight additional cost if it is desired to have sprinkler spacing conform to tree spacing.

Photo No. 10 shows a high capacity sprinkler that operates at pressures between 80 and 120 psi and discharges 200 to 600 gpm. These sprinklers are spaced about 200 feet apart since they will sprinkle an area 400 feet in diameter when discharging 500 to 600 gpm. Because of the high pressures required and the wind interference to the distribution of water, they have not become popular in the western states.

Photo No. 10—Large volume sprinkler capable of discharging up to 600 gpm.

Planning the Irrigation System

Time Required For Irrigation

In many places where surface-irrigation methods are used, a large flow of water is used for short periods and is delivered under a rotation system. An irrigation may be completed on a fairly large tract within a few hours time.

For example, a grower on the Gila Project in Arizona may use an irrigation head of 15 cubic feet per second to irrigate a 40-acre tract, sufficient to apply 3 inches depth of water on the 40 acres in eight hours. A stream of this size for sprinkler irrigation is not practical because of the high costs of the large distribution system and pumping equipment that are required.

The cost of equipment can be reduced to a minimum with a continuous irrigation program during the growing season. Many of the sprinkler systems in operation in the West are used twenty-four hours a day during the irrigation season. With a plan of continuous irrigation a water supply of 5 to [illegible] gpm per acre will often equal crop demands. Sprinkler systems are used only 12 to 18 hours each day in some areas and are shut off at night by using electric timers or by limiting the amount of fuel for gasoline- or Diesel-engine-driven units.

One man can move a quarter mile of lateral pipe in about one hour. If water is applied rapidly and laterals are moved every few hours, the pipe moving operation may be a full-time job for one or two men depending upon the amount of equipment being used. Seven hours of sprinkling with an hour required to move the pipe enables three changes each day for a lateral, but one move must be made late at night or early in the morning.

It is undesirable to move pipe at night since it is difficult to carry and place the pipe in the correct location. Eleven hours of sprinkling with an hour required to move pipe provides two changes each day for a lateral. This is one of the most practical schedules since the lateral changes on many of the smaller farms can be handled as a chore by the grower or by his hired help.

Crop-Water Requirements

Sprinkler systems should be designed by trained men who have information on local soils and on water requirements of the crops. All crops do not require the same amount of water, and the same crop grown under different climatic conditions may result in a wide variation in the amount of water consumed.

Evaporation and plant use are greatest during the summer months and an irrigation system must be designed with sufficient capacity to supply the crop requirements and losses during the period of peak demand. Table 2 can be used as a guide in determining the capacity required for a proposed sprinkler irrigation system, but does not include an allowance for sprinkler evaporation.

Water Losses

Water losses that ordinarily occur with surface irrigation are deep percolation, evaporation, and runoff at the end of the furrow or check. Losses due to percolation and runoff can be almost entirely eliminated by the use of sprinklers.

Evaporation loss is usually higher for sprinkling than for the surface

TABLE 2.—A general guide to aid in determining the peak daily use of water by crops under Arizona conditions.

CROP	Peak use of water per day	
	Above 3,000 ft. elevation	Below 3,000 ft. elevation
	inches	inches
Alfalfa	.15 — .25	.25 — .30
Cotton	.15 — .25	.25 — .30
Pasture	.12 — .20	.20 — .25
Grain	.15 — .20	.20 — .22
Potatoes	.12 — .14	.14 — .16
Vegetable Crops	.12 — .15	.15 — .20
Orchard (deciduous)	.15 — .20	.20 — .25
Citrus		.25 — .30

method of irrigation. Fine spray may also be carried away by wind from the intended area of application in addition to the loss by direct evaporation.

Evaporation losses are particularly important in Arizona because of the combination of low relative humidity, high temperature and intense solar radiation. A study being carried on near Tucson by the Agricultural Engineering Department of The University of Arizona indicates that losses due to evaporation of the spray in the air and to wind drift may reach a peak of 15 to 25 percent of the water applied during the middle of the day in the summer. For night applications the evaporation losses are relatively low and may amount to no more than 5 percent in the early morning hours, even in the summer.

It is necessary for design purposes to allow an average of 10 to 15 percent evaporation loss for day applications, and 5 to 10 percent for night applications. Additional allowances must be made for evaporation from wet ground.

Sprinkler irrigation is not suitable for areas having winds of high velocity during the irrigation season. In areas where such winds are infrequent, temporary adjustments can be made by setting the sprinkler laterals closer together and decreasing the sprinkler spacing in the lateral. In some instances high wind velocities may require plugging the spreader nozzle of the double-nozzle sprinkler; however, if only the range nozzle is used, closer spacing of the sprinklers is necessary to obtain uniform distribution. Water-droplet size is then relatively large with the result that drift losses are reduced.

Water-Holding Capacity Of Soil

The water-holding capacity of the soils in the root zone depends upon the depth and texture of the soil. Available water, or the amount of water that plants can extract from a soil, may be expressed in inches of water per foot of soil.

The total available water is determined by the depth to which plant roots will penetrate. Not over 4 feet of soil, however, should be considered in determining the amount of water available since most plants obtain most of their moisture from the top 3 or 4 feet of soil.

In general, sands or loamy sands can hold 0.5 to 0.75 inches of available water per foot of depth, sandy loams from 1 to 1.5 inches, and silts and clay loams from 1.5 to 2.0 inches. A clay loam then may be able to hold several times as much plant-available water as a loamy sand, and irrigations may be less frequent. A substantial saving in time and money can be realized by the farmer if he will become familiar with his soil types, crop moisture requirements, and necessary frequency and duration of water applications.

Frequency Of Irrigation

The amount of plant-available water stored in the root zone and the maximum rate of use by crops will determine the longest interval that can be allowed between irrigations. It is advisable to irrigate when one-half to three-quarters of the available water in the root zone has been depleted.

For example: Assume a crop will use water at a maximum rate of 0.25 inches per day during a hot summer period, and has a uniform root system extending to a 4-foot depth in a silt loam that holds 2.0 inches of available water per foot of depth. Half of the available water will be used in sixteen days and three-fourths in twenty-four days. The period between irrigations should therefore be from two to three weeks. However, if the root system is concentrated in 1 or 2 feet of soil, more frequent irrigation will be required.

Information regarding soil types and moisture holding capacities are available from local County Agricultural Agents.

Rate Of Water Application

The maximum rate at which water should be applied to a soil is dependent upon the infiltration rate of the soil. Sandy soils will absorb water readily while some clay soils are almost impervious. All available information on a particular soil should be obtained so that the rate of application to be used will not exceed the infiltration rate of the soil.

High rates of application, even on open soils capable of absorbing water at high rates, may not be advisable since the laterals will have to be moved too often to allow the arrangement of a convenient labor schedule. If laterals are to be moved two or three times a day, rates of 0.25 to 0.50 inches of water per hour will be needed in most cases. If laterals are to be moved more frequently and operation is to be continuous, night moving will be required.

Slow application rates may be undesirable in hot climates since the evaporation loss increases with the time of application. The application in inches per hour for various sprinkler discharges and spacings is presented in Table 3, page 17. The rate of application for any sprinkler can also be determined from the following formula:

$$\text{Application in inches per hour} = \frac{\text{gpm} \times 96.3}{\text{area}}$$

gpm = discharge in gallons per minute per sprinkler

area = distance in feet between sprinklers in the lateral multiplied by distance in feet between laterals.

TABLE 3.—Average depth of application in inches per hour from sprinklers for various spacing of laterals and sprinkler intervals.

Spacing in feet	Discharge in gallons per minute per sprinkler head												
	1	2	3	4	5	6	8	10	12	15	18	20	25
	.in	.in	.in	.in	.in	.in	.in	.in	.in	.in	.in	.in	.in
20 x 20	.24	.48	.72	.96	1.20	1.44	1.92						
20 x 30	.16	.32	.48	.64	.80	.96	1.28	1.60	1.93				
20 x 40	.12	.24	.36	.48	.60	.72	.96	1.20	1.45	1.81			
20 x 50		.19	.29	.39	.48	.58	.77	.96	1.16	1.44	1.73		
30 x 30		.21	.32	.43	.54	.64	.86	1.07	1.28	1.61	1.93		
30 x 40		.16	.24	.32	.40	.48	.64	.80	.96	1.20	1.45	1.61	
30 x 50		.13	.19	.26	.32	.38	.51	.64	.77	.96	1.16	1.28	1.60
30 x 60		.11	.16	.21	.27	.32	.43	.53	.64	.80	.96	1.07	1.53
40 x 40		.12	.18	.24	.30	.36	.48	.60	.72	.90	1.08	1.20	1.50
40 x 50			.14	.19	.24	.29	.38	.48	.58	.72	.86	.96	1.20
40 x 60			.12	16	.20	.24	.32	.40	.48	.60	.72	.80	1.00
40 x 80					.15	.18	.24	.30	.36	.45	.54	.60	.75
50 x 50					.19	.23	.31	.39	.46	.58	.69	.77	.96
50 x 60					.16	.19	.26	.32	.39	.48	.58	.64	.80
50 x 70						.17	.22	.28	.33	.41	.49	.55	.69
60 x 60						.16	.21	.27	.32	.40	.48	.53	.67
60 x 70						.14	.18	.23	.27	.34	.41	.46	.57
60 x 80						.12	.16	.20	.24	.30	.36	.40	.50
70 x 70									.24	.29	.35	.39	.49
70 x 80									.21	.26	.31	.34	.43
70 x 90									.18	.23	.28	.31	.38
80 x 80										.23	.27	.30	.38
80 x 90										.20	.24	.27	.33
80 x100										.18	.22	.24	.30
100x100										.14	.17	.19	.24

Water Supply

Sources of water supply which are often used for a sprinkler system are ponds, rivers, irrigation and drainage canals, and wells. In Arizona, wells are the principal source of water supply, and in the case of a well the operator may have some choice in its location. This is a distinct advantage in reducing the length and in some cases the size, of main-line pipe required for a system.

An open water supply will always contain foreign matter, such as floating debris, insects, algae or moss, and silt or sand which will plug sprinkler nozzles and even pipe lines if left totally unprotected. Strainers or screens and in some instances desilting basins must be provided as a part of the sprinkler system.

Apart from the effect of the chemical quality of the water on plant growth its salt content and alkalinity should be considered in connection with the material used in the pipe lines. Highly concentrated salt solutions as the result of evaporation of water remaining at low points in a pipe line may result in rapid pitting or corrosion. An extremely small soluble copper content in the water will also cause rapid decomposition of aluminum.

Field Arrangement Of A Sprinkler Irrigation System

The objective in planning the arrangement of a sprinkler irrigation system is to provide an adequate water supply with uniform distribution at the lowest cost. The arrangement of a system in a field depends upon the location of the water supply, the size and shape of the field, the topography of the land, and the type of farming. In

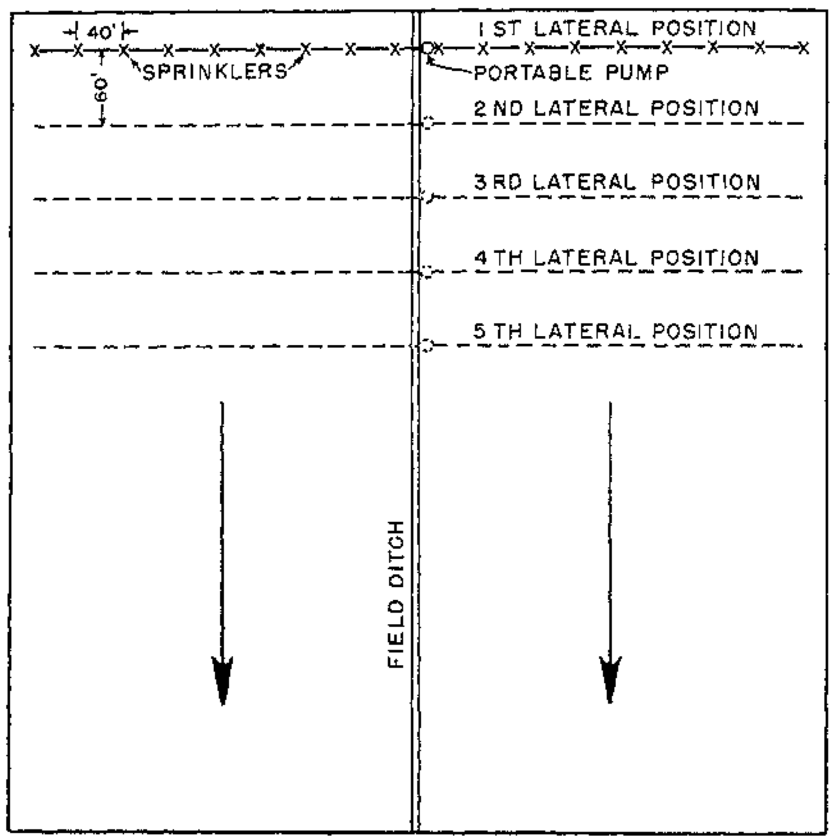

Figure 1.—A field arrangement using two sprinkler laterals and a portable pump that is moved along a field ditch.

general, main pipe lines are located in the direction of the principal slope and laterais at right angles, or on the contour. Extreme variation in elevation within the length of a lateral will result in noticeable differences in the discharge of the sprinklers.

The ideal situation in so far as both main lines and laterals is that in which the flow is in the direction of the slope and the latter is just equivalent to the friction loss in the lines. In the case of extreme slopes it may be necessary to provide for pressure regulation valves in the main line, laterals or at individual sprinkler heads.

Normally no more than two sizes of pipe are considered desirable in a distribution system. Thus pipe can be used inter-changeably at any place on the farm. The larger size is used for the main lines, with sufficient capacity to supply several laterals.

Present practice indicates that laterals up to 4 inches in diameter and not much over 1/4-mile in length are preferred. Portable main lines, up to 8 inches in diameter, are often used, but where larger pipe is required the general practice is to install a permanent main, of either buried or surface pipe.

Figure 1, page 18, illustrates the use of an open ditch to take the place of a main pipe line. The portable pumping unit receives its water direct from the ditch and is moved at the same time the laterals are shifted. This arrangement requires careful screening at the pump suction pipe.

It is also difficult to regulate the flow in the ditch to exactly equal that of the pump discharge and in practice the system is only to be recommended where excess water flows in the ditch. The trailer-mounted pump, with direct-connected air-cooled power unit shown in Photo No. 11 is suitable for this type of installation.

Photo No. 11—A portable pumping unit with air-cooled gasoline engine direct-connected to a 4-inch centrifugal pump used for sprinkler irrigation of permanent pasture near Hereford, Arizona.

Figure 2 illustrates an economical arrangement if the water supply is located in the center of the field to be irrigated. One or more laterals can be used depending upon the rotation period desired. A portable main line equal to half the length of the field is required since it can be moved from one side of the pump to the other. Many growers prefer to use full length main lines, however. The installation shown in Photo No. 12 is located in the center of a 40-acre field. In this case a horizontal centrifugal pump is used to boost the pressure from the deep well turbine pump.

The Supply Line

Where a distributing main cannot be connected directly to the source of supply a supply line is required. Efficiency of distribution of a sprinkler system is not affected by the friction loss in the supply line. The size of pipe used may

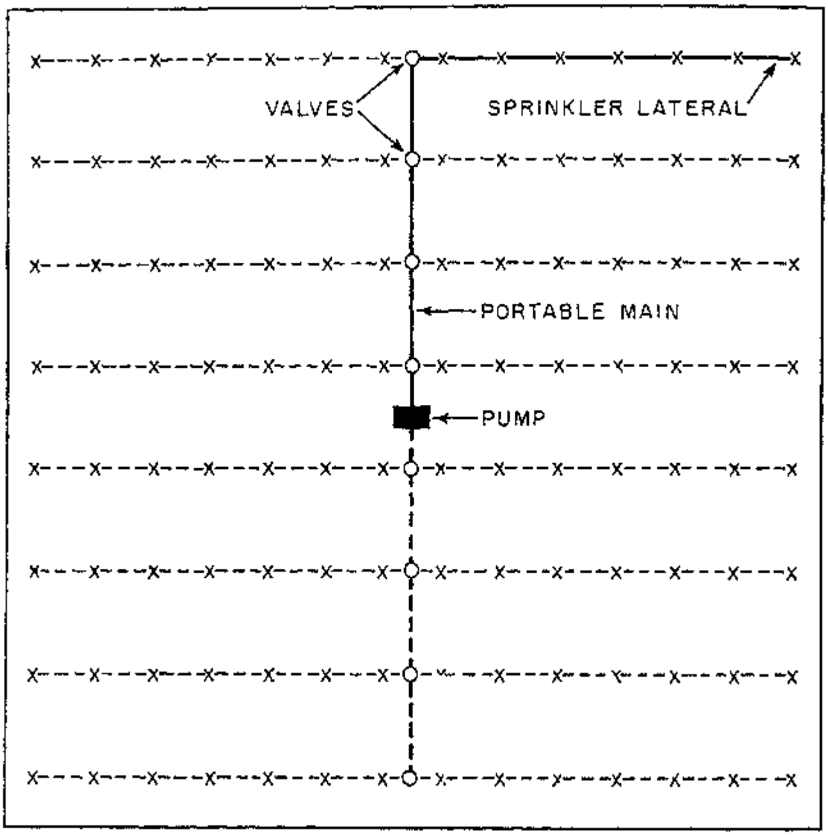

Figure 2.—A common arrangement of a portable sprinkler system with a water supply in the center of the field. The number of laterals in operation at one time depends upon the capacity for which the system is designed.

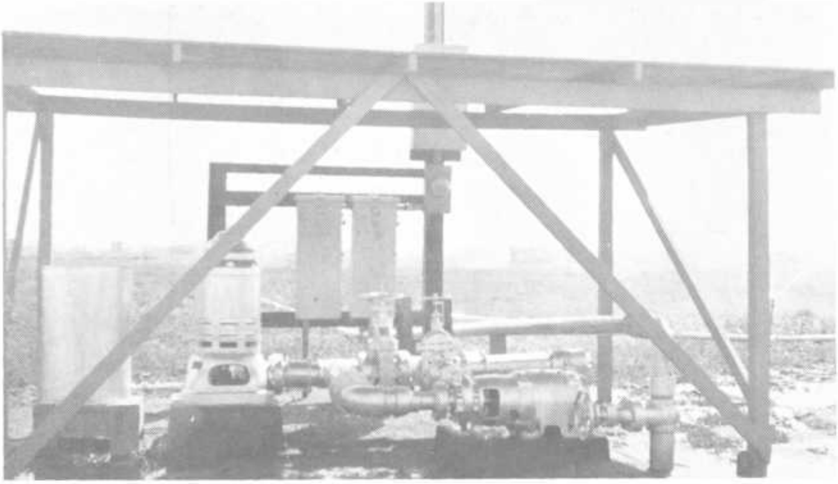

Photo No. 12—Electric motor-driven centrifugal pump used as a booster with a deep well turbine for sprinkler irrigation near Tucson, Arizona.

therefore be determined upon the basis of the lowest estimated annual cost.

In computing the annual cost of several different pipe sizes only the important items of fixed cost, depreciation and interest are considered, and only the fuel or power cost required to pump against the friction head in the supply line is included. The other cost items omitted will ordinarily have negligible effect upon the annual cost and if included, greatly complicate computations.

Annual depreciation is usually computed on a straight-line basis, that is, the initial cost divided by the expected life of the pipe line and is expressed as a percent of the cost. Interest is computed at the going rate on the average investment, or one-half the original investment. The fuel or power cost is computed on the basis of the estimated number of hours of operation per year and assumed conditions for pumping plant efficiency, power rates, and pump capacity. The computations of annual costs can be made upon the basis of 100 feet of pipe line.

The annual power cost in an electric-motor-driven plant to overcome friction in 100 feet of pipe is obtained from the formula given below, in which Hf = the friction loss in feet per 100 feet of pipe, T = annual hours of operation, C = power cost in dollars per kilowatt hour, Ep = overall plant efficiency of pump and motor, and Q = pump discharge in gallons per minute. Corresponding formulas for the computation of annual power costs for engine operated pumping plants are given in Appendix E.

$$\text{Annual Power Cost} = \frac{Q \times Hf \times T \times C \times .746 \text{ dollars}}{3960 \times Ep}$$

TABLE 4.—Comparative annual costs of using different sizes of buried steel pipe for a capacity of 500 gallons per minute; assuming twenty-year life, interest at 6 per cent per annum and electric power at 1.25 cents per kilowatt hour for 3,000 and 1,500 hours yearly use.

Pipe Diameter	Approximate Installed Cost Per 100 feet	Fixed Costs,* & Interest and Depreciation	Annual Power Cost to Overcome Friction per 100 feet Pipeline		Total Annual Cost per 100 feet Pipeline	
			3,000 hrs.	1,500 hrs.	3,000 hrs.	1,500 hrs.
inch	dollars	dollars	dollars	dollars	dollars	dollars
6	100	8.00	12.07	6.04	20.07	14.04
7	125	10.00	5.71	2.86	15.71	12.86
8	150	12.00	3.06	1.53	15.06	13.53
10	190	15.20	1.00	.50	16.20	15.70

* Fixed costs include interest at 6 percent of the average investment cost (3 percent of the initial cost) and depreciation at 5 percent per annum.

To illustrate how the investment cost and the number of hours of operation per year affect the annual costs, a problem has been worked and the results are given in Table 4. The comparative annual costs have been determined for the installation of 6-, 7-, 8-, and 10-inch buried steel supply lines for both 3,000 and 1,500 hours annual operation. It has been assumed that the electric-motor-driven pumping plant has an overall efficiency of 60 percent and a capacity of 500 gallons per minute under average operating conditions. The power cost is 1.25 cents per kilowatt hour. The friction loss per 100 feet of 6-, 7-, 8-, and 10-inch pipe as given in Table 7, Appendix C, is respectively 2.05, .97, .52, and .17 feet.

The results given in Table 4 show clearly the effects of the initial cost and the relation of the number of hours of expected operation to the total annual costs. Thus a sprinkler system operating for only a short period each year would be designed with a comparatively small diameter line. The fixed costs predominate and the pumping costs of pumping against the larger friction head is not the controlling factor.

The Main Line

The main line operates under variable conditions of both flow and pressure and the entire line is not in continuous use during irrigation. Factors which influence the selection of the size of the main line are topography, arrangement of fields, relative location of laterals, the length of the main, and the head capacity characteristics of the pump.

The sprinkler system is usually designed to deliver the required capacity at the location on the main line requiring the maximum head on the pump, and ordinarily this location will be at the most distant laterals. The maximum deviation in pressure and discharge from design conditions of operation will occur when the closest laterals are in operation. The sprinklers in these laterals will operate at higher than the design pressure and discharge more water. The uniformity of distribution is somewhat poorer than under the design conditions.

If the diameter of the main is sufficiently large so the friction loss in it, between the above two locations (plus or minus the difference in elevation), is less than 12 to 15 percent of the maximum operating head on the pump the uniformity of distribution will not be seriously affected.

Under certain conditions of topography this method of selecting the size of main line is not applicable. Its size may then be determined on the basis of lowest annual pumping costs using methods somewhat similar to those used in the selection of the diameter of a supply line. However, under these conditions it is probable that either a gate valve on the main line or valves on the lateral will be necessary for pressure regulation.

The selection of the size of the main line is often the most difficult part in the design of a sprinkler system.

Laterals

The general practice is to select a size of lateral such that the pressure variation in the line will not exceed 20 percent of the operating pressure at the nozzles. This conforms closely with the design specifications as recommended by the Subcommittee[1] of the American Society of Agricultural Engineers on Sprinkler Irrigation. This limitation in pressure range will result in a maximum variation of approximately 10 percent in the discharge from the sprinklers on the line. The resulting coverage is considered sufficiently uniform for practical purposes.

The variation in the pressure in the lateral is due to the friction loss in the pipe plus or minus the head gained or lost by the rise or fall of the land. If the lateral is laid on a contour the pressure drop in the line is equal to the friction loss in the pipe. This drop in pressure or loss in head may be expressed in either pounds per square inch or in feet of head of water. (1 lb. per sq. in. = 2.31 feet head of water)

Because the flow in a lateral varies from a maximum, equal to the combined discharge of all the sprinklers on the line at the inlet, to a minimum at the end of the line, equal to the discharge of a single sprinkler, the computation of the loss of head due to friction is complicated. These computations may be avoided and either the friction loss in the pipe or the size of pipe determined by the use of the nomograph given in Appendix B. To use the nomograph chart the spacing of the sprinkler heads on the line, the number of sprinklers and the discharge per sprinkler must be known.

Pumping Plant

A water supply under pressure is available to the farmer in relatively few instances and ordinarily it is necessary to install a pumping plant to provide water under pressure for a sprinkler system. The pumping plant usually consists of a centrifugal pump, either of the horizontal centrifugal or deep-well turbine type, and its driving unit. The latter may be either an electric motor or an internal combustion engine using gasoline, Diesel

[1] A.S.A.E. Subcommittee on Sprinkler Irrigation. 1951. Minimum Requirements for the Design, Installation and Performance of Sprinkler Irrigation Equipment, Agricultural Engineering, V 32, No. 3.

oil, natural gas or liquified petroleum gas for fuel.

A horizontal centrifugal pump is adapted to use where the distance from the pump base to the water surface is not over 15 feet, such as lifting water from an irrigation ditch, drainage canal, lake, pond, river channel, or shallow well. If the depth to water is greater or fluctuates widely the use of a deep-well turbine pump is probably advisable.

Where the water supply is from a well already equipped for surface irrigation, the pressure unit for the sprinkler system serves only as a booster from the pump discharge or possibly from a storage reservoir. Maximum utilization of an extremely small well in conjunction with a storage reservoir may be obtained with part-time operation of a sprinkler system.

Many systems are designed for the operation of a deep-well pumping unit discharging directly into the main lines of the sprinkler system. This arrangement will not ordinarily be efficient where the pump is used for both surface and sprinkler irrigation.

The characteristics of a centrifugal pump are such that at any particular speed it will operate at high efficiency through a limited range in discharge and head or lift. Therefore, a pump should be selected for the particular discharge and head conditions of each special case. This explains why it is so seldom possible to use a second-hand pump in a sprinkler system which is designed for low cost operation.

The electric motor is a most satisfactory source of power for the operation of a centrifugal pump and when equipped with the proper electrical controls and safety devices it requires a minimum of attention, maintenance or repairs. The electric motor will develop its full rated horsepower output and may safely be overloaded as much as 10 percent under normal temperature conditions. It is ideal for direct-connection to a centrifugal pump, but when so connected the pump operates at constant speed and its discharge-head relations cannot be changed.

Portable engine units must be used where electric power is not available or where electric power rates are high in comparison with fuel costs. Factory ratings of horsepower output of engines are seldom made on exactly the same basis, but all are rated under ideal conditions at the factory. It is not safe to select an engine on the basis of its nominal horsepower rating and expect it to deliver that much power under continuous load conditions, such as a pump load.

The output of an engine is reduced about 3 percent for each 1,000 feet above sea level at which it is operated. It is also slightly affected by operation at extremely high temperatures. Many engineers specify that a medium—or even heavy—duty type of engine shall not operate at more than 75 to 80 percent of its maximum continuous horsepower rating.

The selection of a high-speed, automotive type, light-weight engine for pumping loads should be checked carefully with the manufacturer's agent before purchase. In all cases a Diesel, gasoline or gas engine should have a governor for protection if the pumping load is released.

The engine-driven unit has somewhat more flexibility than the electric-motor-driven unit. Some change in pump speed may be secured by governor regulation without seriously affecting the horsepower output of the engine and wide ranges in speed may be obtained by change in pulley sizes of belt-driven units.

A change in pulley ratios should not be made except upon the advice of a responsible and qualified representative of the sprinkler company from whom the equipment was purchased and who is acquainted with the pump characteristics and the horsepower output of the engine. This is extremely important since the horsepower requirements of a centrifugal pump increase about as the cube of its speed. Thus an increase of 10 percent in the pump speed will increase the load on the engine by over 30 percent.

Power Requirement

The theoretical or water-horsepower required to lift water is computed from the number of foot-pounds of work done each minute divided by 33,000—the number of foot-pounds per minute in a horsepower. A simple formula from which the water horsepower may be computed follows.

$$\text{W. H. P.} = \frac{Q \times H}{3960}$$

In which, W.H.P. = water horsepower or theoretical horsepower. Q = discharge of pump in gallons per minute. H = total head in feet, consisting of the sum of the following:

(1) Vertical distance from water surface at source of supply to the highest point in field to be irrigated.

(2) Friction loss in main pipe line.

(3) Friction loss in lateral line.

(4) Riser height, usually about 1.5 feet.

(5) Required pressure at most distant riser in feet of head. (Pressure in lb. per sq. in. $\times$ 2.31)

The water-horsepower or theoretical horsepower is the power which would be required at the pump shaft if it were possible to secure a pump which would operate at 100 percent efficiency. Pump efficiencies usually range between 50 and 70 percent depending upon their design and the conditions under which they are operating. The actual horsepower which must be delivered to the pump shaft is the water horsepower divided by the efficiency of the pump. The brake horsepower is the horsepower output of the electric motor or engine and it must be large enough to meet the actual power requirements of the pump plus any transmission losses.

The transmission losses consist of belt friction losses or the losses in the gear-head. These are small as the transmission efficiency is usually between 90 and 95 per cent. The brake horsepower output of the motor or engine is equal to the water horsepower divided by the product of the pump efficiency and the transmission efficiency.

The layout and computations necessary to determine the power requirements for a small sprinkler system are illustrated in Figure 3. (See drawing at top of page 26). The computed brake horsepower at the pump is found to be 6.3, which will require the use of a 7.5 horsepower electric motor, the nearest commercial size. In case an engine drive is necessary, then a larger unit must be provided with a horsepower rating of between 8 and 10 horsepower for continuous duty.

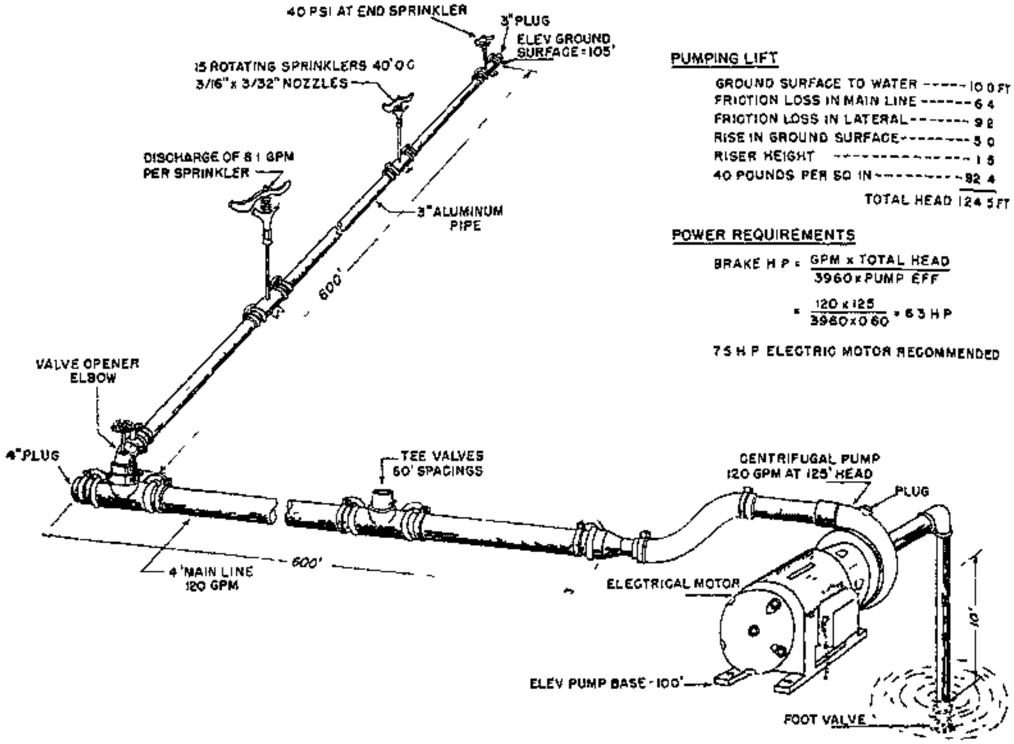

Figure 3.—A small electric motor-driven pumping plant with portable main line, lateral, quick couplings, valve-opener elbow, Tee-valve, and sprinkler heads. Computations of total pump lift and power requirements for a capacity of 120 gpm are shown.

Costs of Sprinkler Irrigation

The total annual costs of sprinkler systems consists of the fixed costs, operating costs, and labor costs. The latter is sometimes included as a part of the operating costs. An example of the computation of these costs is given in Appendix A for a system on a 60-acre field.

Fixed Costs

Those costs which are more or less fixed and do not vary from year to year are termed fixed costs. Interest on investment, depreciation of equipment, insurance and taxes are usually included in the fixed costs. In the case of a sprinkler system which is used primarily for supplemental irrigation and only for a limited part of the crop season the fixed costs may easily constitute the major annual cost of operating the system. Low annual costs per unit of water applied can only be obtained by maximum use of the capacity of the sprinkler system.

Depreciation is difficult to estimate and it is computed on the basis of the expected life of the various parts of the system. In the straight line method the annual depreciation is computed by dividing the original cost of an item by its expected life, assuming that for all practical purposes its value at the end of that period is negligible.

The computation of depreciation separately on the different items of equipment is hardly justified on the basis of estimated life and an average value is usually taken to cover the entire capital investment. Thus the expected life of the pump might be from twelve to fifteen years, of the electric motor twenty years, pipe lines about fifteen years, sprinkler heads six to eight years, and an engine ten to twelve years. An average value of 7 to 8 percent might be taken as a fair estimate for the depreciation rate on the overall investment.

Interest rates are fairly well established in most communities and the going rate should be used in computing the annual interest costs on the basis of one-half of the initial investment cost. One-half the original cost is used because the equipment is being depreciated over the period of its expected life.

Taxes should be estimated upon the basis of local conditions as to assessment practices and rates. In some instances equipment of this type may not be placed on the assessment rolls at all. Insurance is carried by some operators on all their equipment, but if equipment is not covered, then the operator assumes the risk and over a period of years it appears as a part of the operating costs as repairs.

Operating Costs

Operating costs are for fuel or power, repairs, lubricating oil and attendance, and these increase in proportion to an increase in size of the pumping plant. Except for the power cost these are often negligible in the case of the electric pumping plant.

The power or fuel cost can be estimated on a basis of the prevailing rate per kilowatt hour for the electric motor, nine brake-horsepower hours per gallon of gasoline for gasoline engines, 12 brake-horsepower hours per gallon of Diesel fuel for Diesel engines and 12 cubic feet of natural gas per brake-horsepower hour for natural-gas engines.

Brake horsepower can be calculated from the water horsepower by assuming a pump efficiency and the electric energy can be determined by assuming a motor efficiency.

Table 5 gives the power of fuel cost per acre-foot of water per foot of lift for different types of pumping plants at assumed electric energy rates and cost per gallon of fuel. (See page 28).

From this cost comparison, it is evident that operation on natural gas results in the lowest power cost. This advantage is partially offset by the depreciation rates that must be used for natural-gas engines and the necessary repairs and attendance. Electric power is generally the most satisfactory to use

Table 5.—Fuel or electric energy consumption and costs for pumping water.

Type of Plant	*Fuel or Electric Energy Consumpition per Acre-Foot per Foot of Lift	Assumed Unit Cost of Fuel or Electricity	Fuel Cost of Pumping One Acre-Foot of Water per Foot of Lift
Natural gas	27.6 cu. ft.	30.0¢ per 1,000 cu. ft.	0.8¢
Electric	1.9 kwh	1.0¢ per kwh	1.9¢
Electric	1.9 kwh	1.5¢ per kwh	2.8¢
Diesel	0.19 gallons	13.0¢ per gallon	2.5¢
Gasoline	0.25 gallons	19.0¢ per gallon	4.8¢

*Gasoline engines assumed to be able to deliver nine brake-horsepower hours to the pump per gallon of gasoline, Diesel engines to deliver twelve brake-horsepower hours per gallon of Diesel fuel, and natural-gas engines assumed to require 12 cubic feet of gas to deliver one brake-horsepower to the pump. Electric motors considered 88 percent efficient. Pump efficiency in every case is taken as 60 percent.

for sprinkling if it is not necessary to build long transmission lines at consumer expense and rates are not excessive.

Electric motors are quiet in operation, low in cost, have high efficiencies, and do not require continuous attendance. Diesel engines are generally high in first cost but have operating costs similar to electric motors when compared to electric power at 1.5¢ per kilowatt hour. Gasoline is the most expensive fuel to use, but the first cost of a gasoline engine is comparatively low, and fuel usually is available on the farm. Automobile engines which are not designed for a heavy duty continuous pumping load are being used to some extent for irrigation pumping. They must be kept in good operating condition and loaded lightly if satisfactory results are to be obtained.

Lubricating oil and repairs may be estimated as a certain per cent of the annual fuel cost for internal combustion engine pumping plants. Twenty percent of the fuel cost for gasoline engines, 40 percent for Diesel engines and 50 percent for natural-gas engines should be sufficient allowance for oil and repairs.

Electric motors and starting equipment, when properly installed, usually require little in repairs. Lubricating oil is only a minor expense for either the pump or motor. The annual cost for maintenance and repairs for the electric motor-driven pumping plant may be estimated at between 3 and 5 percent of its original cost.

Pump and engine servicing will require about one hour per day for proper maintenance of the system. The attention required by an electrically operated plant is negligible and no allowance is necessary for this item.

Annual maintenance and repairs to the pipe-line distribution system is subject to considerable variation, depending upon the care used in handling the equipment and the amount it is used. It is believed that not less than 3 percent of the original investment cost should be allowed for these items.

Labor Costs

Labor cost for moving sprinkler laterals is variable depending upon how the system has been planned and also upon the particular crop being irrigated. Pipe moving requires on the average five to eight minutes per hundred feet of lateral when being moved distances of 40 to 60 feet. Systems designed to cover large tracts of land may require one or two men on the job continuously or one man may be required part time to maintain the engine and pump and another man helps move pipe when needed.

It is generally agreed that labor costs can be maintained at a minimum if water is applied at a rate that will require moving laterals not more than two or three times per day. With such a schedule it is possile to handle the moving of pipe as a farm chore, and when used on small acreages the labor usually can be performed by the owner. Laterals are then moved early in the morning and again in the early evening with the remainder of the day free for other farm work.

The type of crop influences the labor requirement as the moving of pipe takes longer in tall growing crops than in low flat growing crops. On the average it takes about 1.0 man-hour per acre per irrigation for row crops.

Wheel-move and drag-type methods of moving laterals are sometimes used to reduce labor requirements. Several types of wheel-move systems are on the market, some are engine driven, and others hydraulic or manually operated ratchet and gear driven. A small tractor is used to pull the drag-type laterals on skids from one side of a main to the other. These methods are adapted to special field and crop conditions and should not be recommended without a thorough knowledge of requirements of the individual installation.

Appendixes

APPENDIX A
A Sprinkler System For 60 Acres

The problem is set up for the design and layout of a 60-acre farm for sprinkler irrigation in a semi-arid climate requiring year-round irrigation. A plot of the farm is shown in Figure 4 and the system is to be designed to meet the following conditions:

1. Farm area—nominal 60 acres (1320 x 1950 ft.)
2. Topography—uniformly level
3. Soil—sandy loam, plant available water holding capacity of 1 inch per foot depth
4. Infiltration rate—0.8 inches per hour
5. Water supply—continuous supply from large ditch on side of field

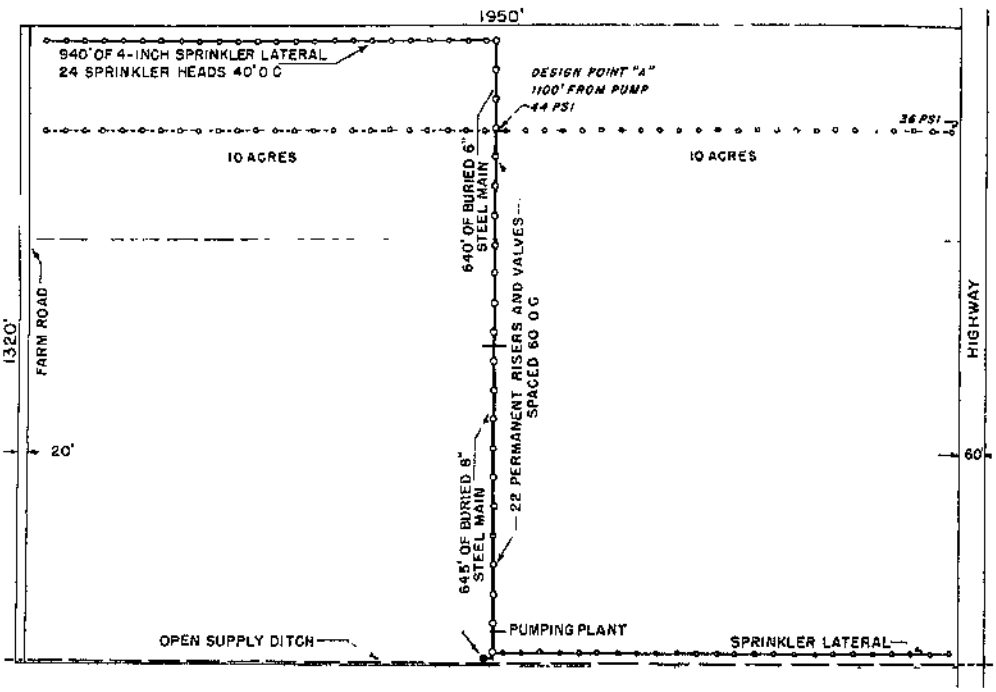

Figure 4.—Field layout showing the location of 6- and 8-inch main line, position of sprinkler laterals, and pumping plant with source of water supply from an open ditch. Sprinkler system is designed on basis of delivering 552 gpm to point "A" with two laterals in operation.

6. Maximum crop water requirements—0.3 inches depth of water per day from upper 3 feet of soil
7. Annual water demand—5 acre-feet per acre
8. Power supply—electric power available at 1 cent per kwh.
9. Sprinkler system—buried steel main and portable aluminum laterals

Solution

Frequency of Irrigation and Minimum Capacity of System—The plant available water-holding capacity of the upper 3 feet of soil in the root zone is given as the equivalent of 3 inches of depth. It is considered desirable to irrigate when only three-quarters of this available supply or 2.25 inches, has been withdrawn. With a peak consumptive use of 0.3 inches per day it will be necessary to replace this water supply every 7.5 days, that is 2.25 divided by 0.3.

It is expected that an irrigation efficiency of application of 70 percent will be obtained. The actual depth of water which must be applied by the sprinklers must then be 2.25 inches divided by the irrigation efficiency of 0.70, or 3.2 inches. The minimum requirements for the entire 60-acre farm during the period of peak consumptive use will then be sixty times 3.20 inches, or 192 acre-inches in the 7.5 days of continuous irrigation. This is at the rate of 25.6 acre-inches per 24-hour day or 1.07 cubic feet per second, equivalent to 482 gallons per minute. A sprinkler system designed with this capacity will provide no factor of safety and in the final design this should be provided.

General Layout for System.—Locate the pumping plant at the center of the south side of the field on the ditch bank and run the main line north through the center of the farm. Plan on the installation of risers and valves spaced at 60-foot intervals on the main line and two laterals with sprinklers at 40-foot spacing operating from the main. Twenty-two risers and valves will be required and with this arrangement the entire farm may be irrigated with forty-four settings.

Since electric power is available for irrigation at the comparatively low price of 1 cent per kwh, a motor-driven, direct-connected, horizontal centrifugal pump will be used. The pump suction and foot valve should be oversize and protected by an adequate strainer to eliminate as much as possible priming trouble.

Rate of Application and Sprinkler Discharge.—It has been previously determined that the desired depth of application per irrigation should be 3.2 inches. If laterals are moved every eight hours and it is assumed that a net of seven hours is allowed for sprinkler operation, the average rate of application will have to be 3.2 inches divided by 7 or 0.46 inches depth per hour.

Size of Laterals.—Twenty-four sprinkler heads, each with a capacity of 11.5 gpm, are needed on each lateral and the total flow in the lateral will be 276 gpm. It is recommended that the laterals be large enough that the friction loss in them will not exceed 20 percent of the average operating pressure at the nozzles, and in this case 20 percent of 40 psi equals 8 psi. From the nomograph in Figure 5 it is found that for a loss of 8 psi a slightly less than 4-inch aluminum pipe is required to supply 24 sprinklers with 11.5 gpm each at 40-foot spacing. Nothing smaller than the 4-inch pipe should be used and the friction loss will for all practical purposes be the entire allowable 8 psi or 18.5 feet.

Size of Main Line.—In this design the main line size will be selected on the basis that it must deliver 552 gpm, the capacity of two laterals, to the midpoint of the most distant 10-acre fields at a distance of 1,100 feet from the pumping plant. It is desirable that the friction loss in the main line (plus or minus the rise or fall) should not exceed 12 to 15 percent of the total operating head of the pump, if satisfactory uniformity throughout the system is to be obtained. In this case it is roughly estimated that the total pumping head will be close to 120 feet, and the upper limit in friction loss in the main should not exceed 15 percent of this or 18 feet, and preferably should be less.

From the data given in Table 7 (page 36) the loss in head due to friction in 6-, 7- and 8-inch welded steel pipe for lengths of 100, 440, 660, and 1,100 feet with a flow of 552 gpm has been computed.

The losses as shown in Table 6 for 1,100 feet of pipe indicate that the 6-inch is too small, the 7-inch very suitable, and the 8-inch is possibly unnecessarily large. The 7-inch pipe is not carried in stock by all dealers and therefore a combination of 6-inch and 8-inch will be used.

If the first 660 feet is constructed of 8-inch pipe and the balance of 6-inch, the

TABLE 6.—Loss of head in feet for 6-, 7-, and 8-inch welded steel pipe for 100, 440, 660 and 1,100 feet with a flow of 552 gallons per minute.

Diameter of Pipe in Inches	Length in Feet			
	100	440	660	1,100
6	2.51	11.0	16.6	27.6
7	1.19	5.2	7.9	13.1
8	0.63	2.8	4.2	6.9

total loss in head to the 1,100 foot design distance will be 4.2 plus 11.0 feet, a total of 15.2 feet. This is well within the estimated limit, of 18 feet, for satisfactory uniformity of distribution.

From the standpoint of annual cost it is believed that by comparison with the results given in Table 4 (page 22) and taking into consideration that the full capacity of the main line is in use less than one-half the total time of irrigation, there is little difference between the three sizes. The main line will consist of 660 feet of 8-inch and approximately 640 feet of 6-inch welded steel pipe.

Pumping Head or Lift.—The total head against which the pump operates will be computed for the condition which would exist if both laterals were in operation at a distance of 1,100 feet from the pump with an average operating pressure at the sprinklers of 40 psi. Under the latter condition the pressure at the far end of the laterals will be only 38 psi., 40 psi less one fourth the 8 psi friction loss in the laterals. The losses as previously computed and estimated are:

Pressure required at end of lateral, 38 psi	87.8 feet
Height of sprinklers above ground	1.5 feet
Friction loss in laterals, 8 psi	18.5 feet
Friction loss in riser and valve	4.0 feet
Friction loss in main	15.2 feet
Lift from water surface to ground surface, including losses in suction and foot valve	5.0 feet
Total head	132.0 feet

It will be noted that the total computed head is greater than the 120 feet assumed in the computations for the maximum allowable friction loss in the main line.. Therefore the friction loss in the main line will be well below the specified allowable upper limits.

Specifications for Pumping Plant.—Previous computations indicate that a pump with a capacity of 552 gpm at a head of 132 feet is required, but a small factor of safety will be added and the specifications will call for a pump which will deliver 552 gpm against a head of 135 feet. The brake horsepower (bhp) required at the pump shaft assuming a pump efficiency at 70 percent is computed as follows:

$$\text{bhp} = \frac{\text{gpm} \times \text{total head in feet}}{3960 \times \text{pump efficiency}}$$

$$= \frac{552 \times 135}{3960 \times 0.70}$$

$$= 26.9 \text{ brake-horsepower}$$

Since the pump is to be direct-connected, electric-motor driven, the motor output will be the same as the brake horsepower of the pump. Electric motors are rated on their horsepower output and under average conditions may be overloaded up to 10 percent of this rating. In this case a 25-horsepower motor will be specified and the motor will operate with an overload of 7.6 percent. However, if it is contemplated that at any time in the future a slightly larger diameter impeller might be installed to increase the capacity or total head, then a 30-horsepower motor would be adequate.

List of Equipment Required and Estimated Installed Cost

2	—4-inch end plugs	
2	—4-inch x 4-inch valve opener elbows	
1880	feet—4-inch aluminum sprinkler lateral with couplings	
48	—1-inch x 18-inch aluminum sprinkler risers	
48	—1-inch aluminum plugs	
48	—1-inch x ¾-inch reducer couplings	
48	—double-nozzle sprinklers	
660	feet—buried 8-inch welded steel main	
640	feet—buried 6-inch welded steel main	
22	—4-inch x 16-inch steel risers for valves	
22	—4-inch riser valves	
1	—Gate valve and pump discharge fittings	
1	—6-inch suction pipe, foot valve and strainer	
1	—25-horsepower, direct-connected horizontal pump unit	
	Total Estimated Installed Cost	$6,900

Total Estimated Cost of Operation of 60-acre System. — The total annual cost consists of the fixed charges based upon the capital investment and the operating and maintenance costs which vary with the number of hours of operation. The number of hours operation necessary to deliver 3600 acre-inches, the required volume to cover 60 acres to depth of 5 feet, is compared as follows:

$$\text{number hours} = \frac{3600 \times 450}{552 \text{ (the discharge of pump in gpm)}} = 2930 \text{ hours}$$

Fixed charges

Depreciation on basis of average life of fifteen years (6⅔ percent of $6,900) .... $ 460.00

Taxes and insurance at 2 per cent of investment 138.00

Interest at 6 percent of average investment (6 percent of ½ of $6,900) 207.00

Operation and maintenance

Power cost—66,800 kwh @ 1.0¢ per kwh 668.00

$$(\text{kwh} = \frac{\text{bhp at pump} \times .746 \times \text{hours operation}}{\text{motor efficiency}}$$

$$= \frac{26.9 \times .746 \times 2930}{.88} = 66{,}800 \text{ kwh})$$

Maintenance and repairs—at 5 percent of investment cost of distribution system and pumping plant 345.00

Labor—estimated cost of moving two 940-foot laterals three times per day for approximately 120 days at $8.00 per day 960.00

Total Annual Cost $2,778.00

Cost per acre-foot (exclusive of the cost of water)

Total acre-feet applied—60 acres at 5-foot depth 300.00

Total annual cost $2,778.00

Cost per acre-foot .... $ 9.26

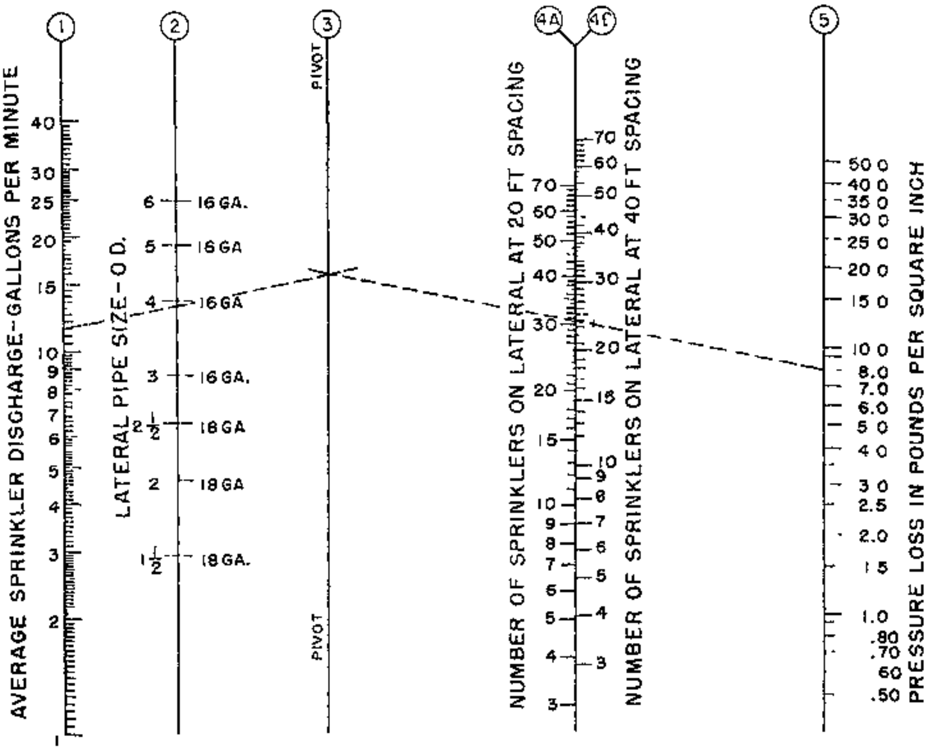

Figure 5.—Nomograph[1] for determining the size of aluminum pipe required for a lateral or the friction loss in a lateral pipe line. (The example shown is for a lateral with an allowable loss in head of 8 psi, twenty-four sprinklers at 40-foot spacing, and a sprinkler discharge of 11.5 gpm. What diameter lateral is required?)

[1] Sprinkler Irrigation Handbook, Rain Bird Sprinkler Mfg. Corp., Glendora, California; prepared by A. W. McCulloch and based on Scobey's formula with values of Ks and multiple outlet factors as recommended by J. E. Christiansen, in "Irrigation by Sprinkling," Bul. 670, University of California.

APPENDIX B

Determination Of Size Of Sprinkler Lateral From Nomograph

The nomograph in Figure 5 is used to determine the size of aluminum sprinkler lateral required to maintain friction losses within certain specified limits and also to determine the friction loss in a lateral of known size under specified conditions of use. An explanation of the procedure to be followed in the use of the nomograph is given below.

Problem: To find the lateral size which will result in 10 percent or less variation in sprinkler discharge.

Given:
(a) Average sprinkler discharge for all sprinklers on lateral,
(b) Average operating pressure at sprinklers, and
(c) Number of sprinklers on lateral.

Procedure:

Step 1. Compute 20 percent of the average operating pressure (b) and locate on Scale 5.

Step 2. Locate the number of sprinklers on the lateral on Scale 4A for 20-foot spacing or 4B for 40-foot spacing. Connect points on Scale 5 and 4A or 4B and extend line to Scale 3, the Pivot Line.

Step 3. Connect point on Pivot Line, Scale 3, with the value for average sprinkler discharge on Scale 1.

Step 4. The required lateral size will be found on Scale 2 at the intersection of the connecting line between the point on the Pivot Line and the point on Scale 1. If the intersect falls between two standard pipe sizes it is advisable to use the larger. However, if expedient to use two sizes of pipe in the lateral the relative length of each size required will be inversely proportional to the distances between the point on Scale 2 and the index pipe sizes on the Scale.

For a sprinkler spacing of other than 20 feet or 40 feet, use the following amendments to the procedure outlined above:

1. Compute 20 percent of the average operating pressure (b).
2. Multiply the value obtained by 20 divided by the spacing and use this value to start on Scale 5.
3. Follow steps 2, 3, and 4 as outlined under procedure, using Scale 4A.

If a lateral of known diameter is to be analyzed for pressure loss reverse the order of the steps outlined in the procedure. For sprinkler spacings other than 20 or 40 feet, multiply the resultant loss obtained on Scale 5 by the spacing divided by either 20 or 40 depending upon whether Scale 4A or 4B was used.

APPENDIX C

TABLE 7.—Loss of head in feet per 100 feet of welded steel pipe.
Table based on Scobey's formula with Ks = .33 for 3″ pipe, and Ks = .32 for larger sizes.

Capacity		Outside Diameter of Pipe in Inches								
gpm	cu. ft./sec.	3″ 16 gage	4″ 16 gage	5″ 16 gage	6″ 16 gage	7″ 14 gage	8″ 12 gage	10″ 12 gage	12″ 12 gage	14″ 12 gage
10	.02	.04								
20	.04	.16								
30	.07	.33	.08							
40	.09	.58	.13							
50	.11	.88	.19	.06						
60	.13	1.24	.27	.09						
70	.16	1.66	.35	.11						
80	.18	2.14	.50	.16	.07					
90	.20	2.70	.60	.20	.08					
100	.22	3.29	.72	.23	.10	.05				
125	.28	5.08	1.14	.37	.15	.07				
150	.33	6.93	1.56	.51	.21	.10				
175	.39	9.50	2.15	.69	.28	.13	.07			
200	.45	12.31	2.70	.87	.35	.17	.09			
250	.56	18.90	4.26	1.38	.56	.26	.14	.05		
300	.67	26.60	5.98	1.94	.79	.37	.20	.06		
350	.78		8.00	2.59	1.05	.50	.26	.09	.03	
400	.89		10.25	3.33	1.34	.64	.34	.11	.04	
450	1.00		12.83	4.15	1.68	.79	.42	.14	.06	
500	1.12		15.64	5.07	2.05	.97	.52	.17	.07	
600	1.34		22.35	7.24	2.93	1.39	.74	.24	.10	
700	1.56			9.66	3.91	1.85	.99	.32	.13	.06
800	1.79			12.41	5.03	2.37	1.27	.41	.17	.08
900	2.01			15.64	6.33	2.98	1.59	.52	.21	.10
1000	2.23			19.03	7.70	3.64	1.94	.63	.25	.12
1200	2.68				10.85	5.13	2.73	.89	.36	.17
1400	3.12				14.61	6.92	3.68	1.20	.48	.23
1600	3.57					8.89	4.74	1.55	.62	.29
1800	4.01					11.16	5.93	1.93	.78	.36
2000	4.46						7.27	2.36	.95	.44

APPENDIX D

TABLE 8.—Loss of head in feet per 100 feet of aluminum pipe with couplings. Table is based on Scobey's formula with Ks = .34 for 2" pipe, .33 for 3" pipe and .32 for larger sizes.

Capacity		2" O.D.	3" O D.	4" O.D.	5" O.D.	6" O.D.	7" O.D.	8" O.D.
gpm.	cu. ft./sec.	.05" wall	.05" wall	.063" wall	.063" wall	.063" wall	.078" wall	.094" wall
2	.004							
4	.009							
6	.013							
8	.018	.21						
10	.022	.32						
12	.027	.45						
16	.036	.78						
20	.04	1.20	.15	.04				
30	.07	2.58	.32	.08				
40	.09	4.49	.56	.13	.04			
50	.11	6.85	.85	.20	.07	.03		
60	.13	9.85	1.21	.28	.09	.04		
70	.16	12.95	1.61	.38	.12	.05		
80	.18	16.70	2.06	.49	.16	.06	.03	
90	.20	20.58	2.58	.60	.20	.08	.04	
100	.22	25.58	3.18	.74	.24	.10	.05	.03
120	.27		4.51	1.06	.34	.14	.07	.04
140	.31		6.00	1.41	.46	.19	.09	.05
160	.36		7.75	1.82	.59	.24	.11	.06
180	.40		9.67	2.27	.73	.30	.14	.07
200	.45		11.83	2.78	.89	.36	.17	.09
220	.49		14.12	3.31	1.07	.44	.20	.11
240	.54		16.72	3.91	1.27	.52	.24	.13
260	.58		19.42	4.56	1.47	.60	.28	.15
280	.62		22.40	5.26	1.71	.69	.33	.17
300	.67		25.45	5.98	1.93	.79	.37	.19
350	.78			8.63	2.59	1.05	.50	.26
400	.89			10.36	3.33	1.35	.64	.33
450	1.00			12.90	4.15	1.69	.80	.41
500	1.12			15.73	5.07	2.06	.97	.50
550	1.23			19.12	6.16	2.50	1.18	.62
600	1.34			22.46	7.24	2.94	1.38	.72
650	1.45			26.10	8.42	3.41	1.62	.84
700	1.56				9.68	3.92	1.86	.97
750	1.67				11.05	4.46	2.11	1.10
800	1.79				12.48	5.03	2.38	1.24
850	1.90				13.95	5.64	2.67	1.39
900	2.01				15.65	6.35	2.98	1.56
950	2.12				17.35	7.02	3.32	1.73
1000	2.23				19.10	7.72	3.64	1.90
1100	2.46				22.85	9.22	4.37	2.27
1200	2.68				26.95	10.88	5.16	2.68
1300	2.90					12.62	5.96	3.10
1400	3.12					14.65	6.90	3.60
1500	3.34					16.67	7.87	4.07

APPENDIX E

Computation Of Annual Power Or Fuel Costs For Pumping

An estimate of the probable annual power or fuel costs for pumping may be made by using one of the formulas given below and substituting the appropriate values in it.

Electric Motor

$$\text{Annual Power Cost} = \frac{Q \times H \times T \times 0.746 \times Ce}{3960 \times Ep \times Em}$$

Gasoline Engine (On the basis that the engine delivers nine brake-horsepower hours to pump shaft per gallon of fuel)

$$\text{Annual Fuel Cost} = \frac{Q \times H \times T \times Cg}{3960 \times Ep \times 9}$$

Diesel Engine (On basis that the engine delivers twelve brake-horsepower hours to pump shaft per gallon of fuel)

$$\text{Annual Fuel Cost} = \frac{Q \times H \times T \times Cd}{3960 \times Ep \times 12}$$

Natural Gas Engine (On basis that engine requires 12 cu. ft. gas per brake-horsepower hour at the pump shaft)

$$\text{Annual Fuel Cost} = \frac{Q \times H \times T \times Cng}{3960 \times Ep \times 83.3}$$

The meaning of the symbols used in the above formulas are as follows:

Q = Pump discharge in gallons per minute
H = Total head on pump in feet
T = Annual hours of operation
Ep = Efficiency of pump in decimal form
Em = Efficiency of electric motor in decimal form
Ce = Cost per kwh of electric energy in dollars
Cg = Cost per gallon gasoline in dollars
Cd = Cost per gallon Diesel fuel in dollars
Cng = Cost per 1,000 cu. ft. natural gas in dollars

The annual power or fuel costs derived from the use of the above formulas will be in dollars. If the fuel consumption of an engine differs from the assumed values the results may be corrected by multiplying them by the ratio of the estimated fuel consumption to assumed values.

The above formulas may be used for computing the annual cost of pumping against the friction loss per 100-feet of pipe line by substituting the friction loss per 100 feet of pipe for the total head. These formulas may be used in computing the annual power or fuel cost per 100 feet of supply line.

APPENDIX F

Convenient Practical Equivalents

Area

1 acre	= 43,560 sq. ft.
	= 66 ft. x 660 ft.
	= 33 ft. x 1,320 ft.

Volume

1 gallon	= 231 cu. in.
1 cu. ft.	= 7.5 gallons
1 acre-inch	= 3,630 cu. ft.
1 acre-foot	= 43,560 cu. ft.
	= 325,851 gallons

Weight

1 gallon weighs 8.34 lb.
1 cu. ft. weighs 62.4 lb.

Rates of Flow

1 cu. ft. per sec.	= 7.5 gallons per sec.
	= 450 gallons per min.
	= 40 miner's inches (Arizona)
1 miner's inch	= 11.25 gallons per min.

Volume from Rates of Flow

1 cu. ft. per sec. for one hour	= 3,600 cu. ft.
	= 1 acre-inch (approx.)
40 miner's inches for one hour	= 1 acre-inch (approx.)
450 gallons per minute for one hour	= 1 acre-inch (approx.)
1 cu. ft. per sec. for twelve hours	= 1 acre-foot (approx.)

Work and Power

1 horsepower	= 550 ft. lb. per sec.
	= 33,000 ft. lb. per min.
	= 0.746 kilowatt
1 kilowatt	= 1.34 horsepower
1 acre-foot water lifted 1 foot	= 1.372 horsepower hours work
	= 1.025 kilowatt hours of work

Pressure and Head

1 lb. per sq. in.	= 2.31 ft. of water
1 in. mercury	= 1.13 ft. of water
1 atmosphere at sea level	= 14.7 lb. per sq. in.
	= 29.9 in. of mercury
	= 33.9 ft. of water

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