UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 495

Contribution from the Office of Public Roads and Rural Engineering
LOGAN WALLER PAGE, Director

Washington, D. C. ▼ February 14, 1917

SPRAY IRRIGATION

By

MILO B. WILLIAMS, Irrigation Engineer

CONTENTS

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By Milo B. Williams, *Irrigation Engineer.*

CONTENTS.

INTRODUCTION.

Within the past 10 years the spray-irrigation method has been adopted over a wide area in the United States, especially in the Atlantic Coast States from Massachusetts to Florida. Many spray-irrigation plants have been installed in the North Central States, while scattered installations can be found in practically all southern and western States.

In spray irrigation water is applied to the surface of soils and to crops in the form of small drops, spray, or mist.[1]

The first systems of spray irrigation were an outgrowth of city lawn sprinkling. It was soon demonstrated that by employing such systems small amounts of water could be applied advantageously to delicate crops, especially for supplementing an uncertain rainfall. This method also was found particularly well adapted for furnishing relatively small quantities of water to truck and small fruit crops throughout the humid region.

[1] Use of Water in Irrigation, by Samuel Fortier.

Note.—This bulletin is of special interest to truck and small-fruit growers of the eastern part of the United States.

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The introduction of gas, oil, and electric power for operating pumps on the farm has provided means of elevating water to the higher lands and generating sufficient pressure to produce the desired spray. Engineers have devised systems of piping and special spray equipment for irrigating all areas by spray methods and have introduced automatic devices which reduce labor.

The object of this bulletin is to familiarize the farmer with conditions under which spray irrigation may be undertaken profitably, suggest possible water supplies, and illustrate typical pumping machinery and distribution systems, so as to aid the prospective irrigator in determining whether spray irrigation should have a place in his farm operations. It is also intended to present information necessary in working out an intelligent design and installation of a spray system.

ECONOMIC CONDITIONS JUSTIFYING SPRAY IRRIGATION.

The cost of spray-irrigation systems depends upon the type installed as well as upon conditions peculiar to each farm. A portable outfit may cost as little as $50 per acre for the field equipment, while a stationary distribution system may cost as much as $150 per acre.[1] To these figures must be added the cost of a main pipe line leading from the water supply to the fields and usually the cost of developing a water supply and installing a pumping plant. These additional items may bring the total outlay per acre up to two or three times the cost of the distribution system, especially on small acreage. Assuming a cost of $250 per acre on a stationary plant for a small acreage, the farmer should be able to increase his annual returns from each acre to cover approximately the following charges:

Six per cent interest on $250	$15.00
Five per cent, depreciation on equipment	12.50
Two per cent, maintenance and repairs	5.00
Cost of fuel and oil at 4 cents per 1,000 gallons of water pumped for 6 acre-inches	[2] 6.50
Labor in irrigating, 1 man 6 days at $2	12.00
Total overhead and operating expenses	51.00

It will be noted that $51 per acre per year is necessary in returns to cover overhead and operating expense incidental to the spray system. To realize a fair profit from the irrigation plant, the crops must increase in value something more than $51 per acre. In the case of berry, tobacco, and orchard crops the increase must be derived

[1] The subjects of lawn and greenhouse irrigation are not included in this bulletin.

[2] Cost of pumping estimated for a plant operating at 50 per cent efficiency against a total head of 150 feet, using gasoline as fuel. The amount of water pumped annually is assumed at 6 acre-inches as a typical duty of water in the Atlantic Coast States where spray irrigation is most extensively used. More arid sections require larger amounts.

from one main crop and a possible intercrop. On the other hand, the irrigator of truck who follows intensive culture has a chance of dividing the annual increase among three to six crops. The high cost of spray irrigation eliminates its use on many crops which respond readily to irrigation. It is possible, however, to use cheaper methods of distribution on many of these crops which are grown on land having an even surface. A combination of spray irrigation and surface methods on the same farm often can be placed under one pumping plant, as illustrated in figure 1, thereby utilizing to the fullest extent the water supply, pumping equipment, and main pipe lines. The typical farm illustrated in figure 1 indicates the use of spray irrigation on the more uneven parts where the topography is not adapted to cheaper methods but where the soil and southern slope are desirable for the growing of early and intensive truck and berry crops that will justify spray irrigation. The main feed pipe is extended to the upper and more even parts of the farm, where cheaper methods of irrigation can be applied to alfalfa, orchard, bush berries, potatoes, and other crops grown in wide rows for horse cultivation.

Truckers in the arid sections seem to favor a combination of spray irrigation and surface irrigation on the same field. The spray is used in the preparation of the seed beds, germinating seeds, and starting newly set plants. Later the crops are irrigated during the maturing and fruiting periods by the surface furrow or check methods. A portable spray equipment often meets these conditions most economically, because it can also be used for the irrigation of hot-bed and cold-frame crops.

Adequate markets, labor, and fertilizer facilities are other essentials for successful spray irrigation. Good roads and equipment for quick hauling of perishable truck and berry crops to a railway or other express service station must be assured unless some valuable annual crop, such as tobacco or onions, which can be cured on the farm, is being grown for deliberate marketing. The express service for irrigated trucking purposes must be able to deliver the products promptly and in a fresh, unwilted state to markets which require a continuous supply of high-grade vegetables. Many of the most successful users of spray irrigation are operating on small areas for the raising of only such crops as can be consumed by the local trade of a small town or community, thus simplifying the transportation question greatly.

Intensive truck or berry growing under irrigation requires a large amount of more or less experienced labor. The irrigator should manage his farm in a way which will enable him to hire men for long periods and reduce the necessity for employing many laborers for short periods. The moisture-supply control given by spray irrigation

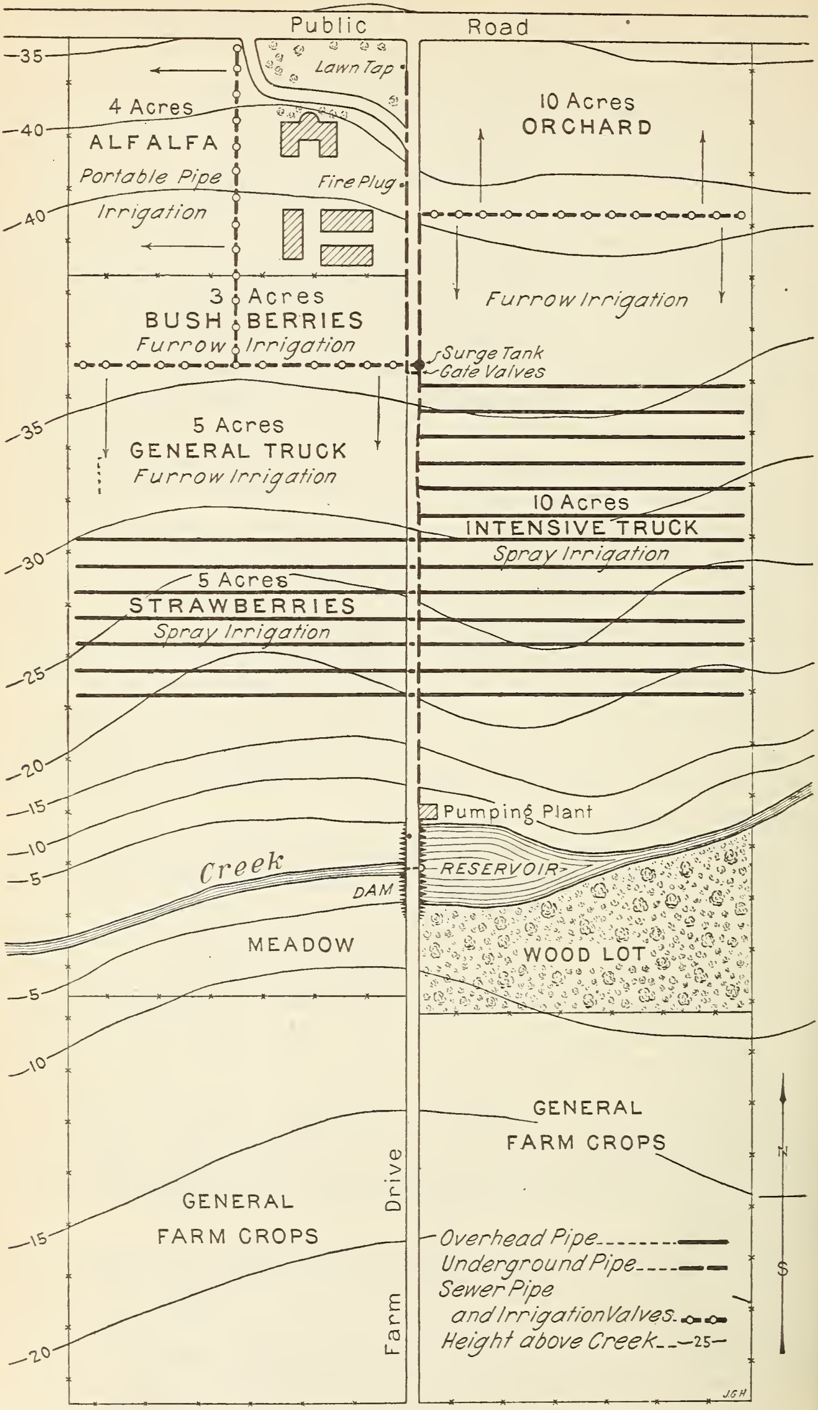

FIG. 1.—Typical 80-acre farm in humid regions, showing development of water supply by reservoir and a combination of spray and surface methods of irrigation operated from one pumping plant.

justifies the farmer in using larger amounts of fertilizers. Truckers near Philadelphia are using profitably as high as 50 tons of manure per acre each year. Therefore, proximity to manure markets is a factor of importance to be considered by the prospective spray irrigator.

FARM CONDITIONS ADAPTED TO SPRAY IRRIGATION.

Where economic conditions are favorable to the adoption of spray irrigation, the most important question then becomes one of an adequate water supply, which will be considered under a separate heading.

Spray irrigation can be practiced to advantage on both light and heavy soils. By this method it is possible to apply evenly to sandy soils the small quantities of water which such soils will retain, without the loss of water by percolation which might occur with other methods. It is possible also to apply to heavy clay soils the small quantities of water required to soften such soils when they have baked after rains, and to apply water no faster than the soil can absorb it, thus preventing loss by surface run-off.

Lands to be irrigated should be drained as completely as possible of excess moisture. Many tile-drained fields are the most responsive to crops under spray irrigation.

Spray irrigation is practically independent of the topography of the field and can be applied to land too rolling or rough for surface methods. It is, therefore, adaptable to the irrigation of side hills on which soils tend to wash or erode.

AMOUNT OF WATER REQUIRED FOR SPRAY IRRIGATION.

As yet, the available knowledge on the amount of water required for spray irrigation is limited, because of the comparative newness of the method and the lack of actual records on plants under a time test. The writer, however, has made estimates in several cases by recording the number of hours a plant of known capacity has been operated with effective results. In the humid regions amounts not exceeding one-fourth inch in depth often are considered a sufficient application to seed beds and young vegetables, while in the case of maturing garden crops and strawberries one-half to 1 inch may be applied. It is probable that truckers in the humid region do not use more than 6 inches in a growing season and in many seasons 4 inches or less will supplement the rainfall sufficiently. More water is required for sandy soils than for clay. A crop like the spray-irrigated citrus groves of Florida may require as much as 3 inches per irrigation. Truck and citrus growers in the arid regions apply more water than those in the humid region, probably because of a large evaporation loss. In the arid region the truck farmer is inclined to make frequent applications—every 3 or 4 days—rather than to apply the extra amount of water required in large applications which will wet below the reach of the vegetable roots, while the citrus grower applies from 4 to 8 inches each time.

For spray irrigation sufficient water to cover the land to a depth of 1 inch per week for humid regions and 1½ inches per week for arid regions is believed to be a safe estimate for designing purposes. A spray plant should be large enough to supply these amounts of water in a reasonable length of time. This is accomplished generally by installing the system to spray from one-fifth to one-half of the total acreage at one time, depending somewhat upon the type of distribution used and the available water supply.

The capacity of a pump usually is stated in gallons of water per minute of time. The following table of equivalents will assist in converting local irrigation units into gallons and acre-inches for estimating purposes:

1 acre-inch equals 27,152 U. S. gallons.
1 acre-inch equals 3,630 cubic feet.
1 acre-inch per hour equals 452.5 gallons per minute.
1 acre-inch per hour equals 1.009 cubic feet per second.

DEVELOPMENT OF WATER SUPPLIES.

The writer will consider here only the water supplies which one or more farmers can develop, for practically all spray-irrigation installations are made by individuals and do not involve the development and transportation of distant supplies, as is common for community irrigation in the arid regions.

There are two sources of water available for irrigation—surface waters and underground waters. Surface supplies include streams, lakes, springs, and stored drainage and rain waters. Underground supplies are obtained from sumps, shallow wells, and deep wells.

SURFACE SUPPLIES.

Streams furnish the greater portion of the water used for irrigation.

In most of the Western States methods of procedure for obtaining the right to take water for irrigation purposes from public streams have been outlined by law. Eastern States, however, have not enacted such laws, and this is apt to restrict the use of water from many streams. This is true especially where the water is being used for developing power, or where the entire flow is taken from the stream, or when a riparian owner exerts his lawful rights. These restrictions are not likely to apply to lakes unless sufficient water is taken to lower considerably the water level in the lake, or the lake feeds a stream. The right to use water from a spring originating on the farmer's land probably never will be questioned.

The use of water for spray irrigation requires a farm pumping plant. The pump should be located as near as possible to the field, so as to avoid a large discharge line, and the suction pipe should be made as short as possible. The vertical suction lift should be kept under 25 feet. The horizontal distance between pump and water should not exceed 300 feet. Where water is taken from a stream or lake having high banks it may be necessary to locate the pump on a made terrace within suction lift of the water, and in extreme cases it may be necessary to so locate both power plant and pump. Many surface supplies are surrounded by lowlands, and under such

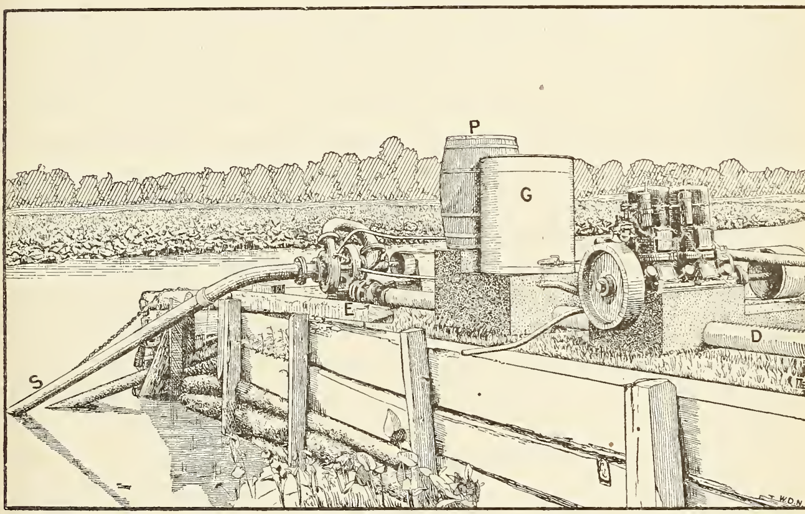

FIG. 2.—Pumping from stream with 2-stage centrifugal pump and gasoline engine, with house removed. Note lack of sharp angles in suction and discharge pipes. *D*, Discharge pipe; *E*, expansion joint; *G*, gasoline tank; *P*, priming barrel; *S*, suction pipe.

conditions the water may be carried to a pumping plant in an open ditch or large tile, permitting the pumping machinery to be located nearer the field and on firm ground. Figure 2 illustrates a pumping outfit located on a farmer's wharf before a house was built. Many eastern streams overflow, and where it is impracticable to place the pumping plant above the high-water line it is necessary to use a portable outfit which can be moved quickly. This usually is accomplished by placing the pump and engine on a set of skids or, with small plants, on wheels. In either case it is well to have a permanently located solid foundation to hold the plant when in operation. A quick method of connecting and disconnecting the discharge and suction pipes should be provided, bolted flange or flexible hose connections being commonly used. Only removable suction pipe should be placed in surface supplies which freeze in winter.

STORAGE WATER.

In many cases excellent water supplies for spray irrigation plants are obtained from streams, drains, and wells which do not have a continuous flow of water sufficient without storage. In such cases the water may be stored in a small reservoir. Figure 1 illustrates a small stream across which an earthern dam has been built at a point where it will back considerable water over a flat area and hold it until the farmer needs to irrigate. In the Eastern States much smaller reservoirs can be used than in the arid regions, because the rains are more frequent and are sufficient to make the small streams flow every few weeks. Likewise in the more humid sections water from farm drains and rain water flowing from hillsides and roofs of buildings can be conserved by storage in reservoirs or cisterns built of clay brick or cement, and in this way many gardens may be saved in dry periods.[1] A section in eastern Pennsylvania is representative of the Eastern States where spray irrigation has developed. The writer estimates from a study of rainfall records and drought periods covering 20 growing seasons in this section that the storage of the water falling on the roof of a building during the summer months is sufficient to irrigate a garden which is three times the area of the building. The reservoir in this case would need to hold about two months' rainfall or the equivalent of 6 inches falling on the roof.

UNDERGROUND WATERS.

Underground waters may be divided into ground and artesian. To the first belong the waters which are nearest the surface and more or less influenced by local rainfall, seepage, and droughts. The waters of the second group are confined under pressure beneath an impervious stratum, usually located at considerable depth below the surface. Such water, when tapped by boring, will rise in the well and sometimes overflow at the surface. The development of underground waters is usually more expensive than obtaining a supply from surface sources. However, when a farmer is able to obtain underground water at a reasonable depth near or in the center of the field to be irrigated the saving in cost of piping may largely offset the expense of sinking wells.

[1] Various types of small reservoirs which would be of value to readers of this bulletin are discussed in Bulletin No. 179, of the Office of Experiment Stations, and part 1 of Office of Experiment Stations Bulletin No. 249. The department's supply of these bulletins has been exhausted, but copies can be obtained from the Superintendent of Documents, Washington, D. C., at a cost of 20 cents each.

A simple way to develop ground water is to dig a sump or pit in a swamp, in a sidehill-spring bog, or in seeped lands bordering a stream or canal. In many cases, where water-bearing sand or gravel can be reached near the surface, the sump furnishes a very cheap water supply which can be enlarged to considerable storage by removal of materials. Pumping from a sump or pit requires the simplest kind of machinery and is a possible source of water for spray irrigation in many of the trucking districts of the East and the surface irrigated districts of the West.

Shallow open wells are a modification of sumps, but generally are deeper and smaller in diameter. Their use as sources for irrigation water usually is limited to special cases where the materials passed through above the water stratum will stand without expensive curbing, and where the water-bearing materials are coarse, resembling gravel or porous rock, and need little screening.

A common way of developing ground water is by the use of one or more well points. A well point (fig. 3) consists of a section of galvanized-iron pipe which is perforated, usually with elliptical holes, and has a sharp iron plug swaged into place in one end and is threaded on the opposite end. The point is screwed into galvanized wrought-iron pipe and driven into the earth to the water-bearing stratum. Extra heavy "guaranteed" wrought-iron pipe should be used if the pipe is to be driven through hard, resistant materials. When used in coarse materials the perforations may be left uncovered, although it usually is necessary to cover the body of the point with a perforated brass jacket to prevent sand being drawn into the pump. Where very fine sand is encountered a fine mesh gauze is placed between the pipe and jacket. For irrigation wells it is advisable to use as large perforations as possible, and many wells which yield considerable sand in the beginning improve in this respect as they are pumped. Points of this type are made up to 4 inches in diameter. Two-inch points and smaller can be driven by hand through soil and sandy materials to a depth of 50 to 75 feet, while those larger in diameter usually require a machine for sinking.

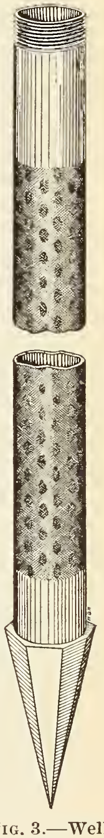

FIG. 3.—Well point.

Piston or plunger pumps may be connected directly to the casing of a driven well when the water comes within suction lift, which is practically 25 feet at sea level and becomes less as the altitude increases (see Table 5). Where the water draws down to a greater distance from the pump it is necessary to sink the pump in a pit, as illustrated in figures 4 and 5. Several points spaced 10 to 50 feet apart may be connected in series to one pump and in this way a con-

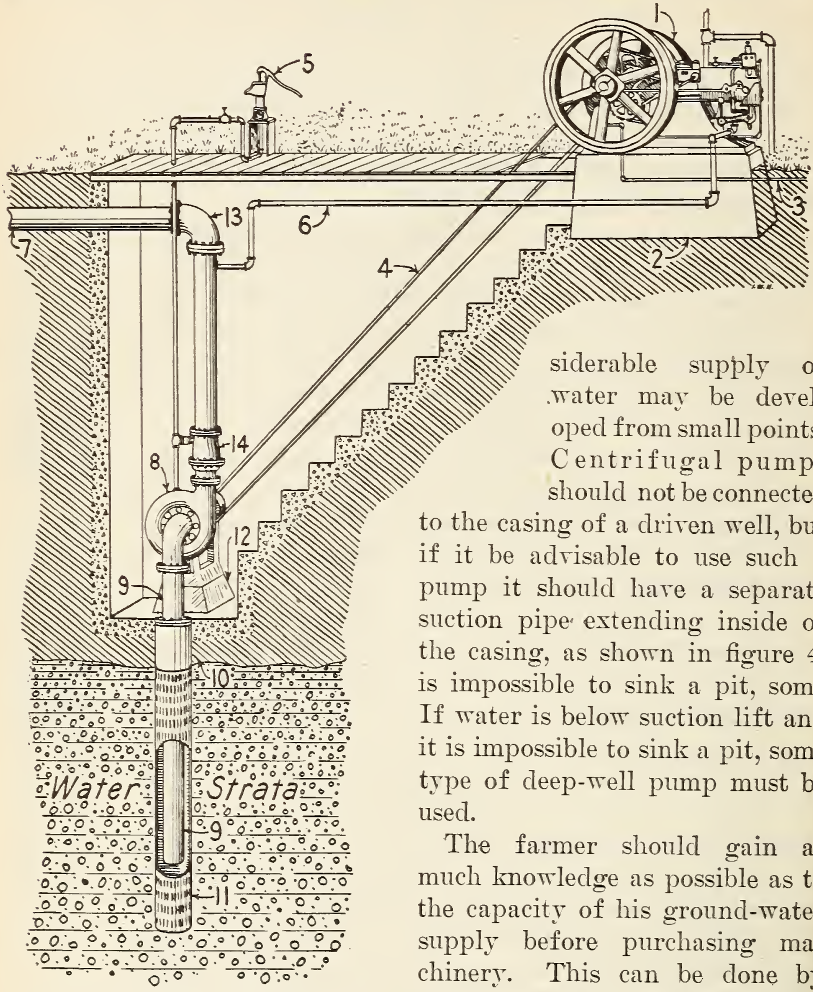

FIG. 4.—Typical installation of horizontal pump in brick or concrete pit with sloped belt. 1, Engine; 2, engine foundation; 3, fuel pipe; 4, belt; 5, priming hand pump; 6, water-cooling pipe for engine; 7 discharge pipe; 8, pump; 9, suction pipe; 10, well casing; 11, well screen; 12, pump foundation; 13, long-turn elbow; 14, check valve.

siderable supply of water may be developed from small points. Centrifugal pumps should not be connected to the casing of a driven well, but if it be advisable to use such a pump it should have a separate suction pipe extending inside of the casing, as shown in figure 4. is impossible to sink a pit, some If water is below suction lift and it is impossible to sink a pit, some type of deep-well pump must be used.

The farmer should gain as much knowledge as possible as to the capacity of his ground-water supply before purchasing machinery. This can be done by sinking a small test well to show what depth and kind of water-bearing materials are present. The test well should be pumped as near to exhaustion as is practicable and from the amount of water obtained the number and kind of wells necessary can be estimated. Two-inch and smaller wells within suction lift can be tested with a common hand pump for short periods up to a flow of 10 gallons per minute, and two men with a double-acting force pump can run tests up to a flow of 20 gallons per minute. Larger and deeper wells require special power equipment for testing.

The boring of deep wells for artesian waters should be undertaken by an expert familiar with the local underground conditions. Determining in advance the probability of obtaining artesian water sufficient for irrigation purposes is a very difficult problem. Geologists familiar with the underground formations and having records of some deep wells in the vicinity upon which to base their judgment often can render a fair opinion. However, it always is more or less a gamble until the well is completed, and a farmer should not take the risk unless he is prepared to lose.

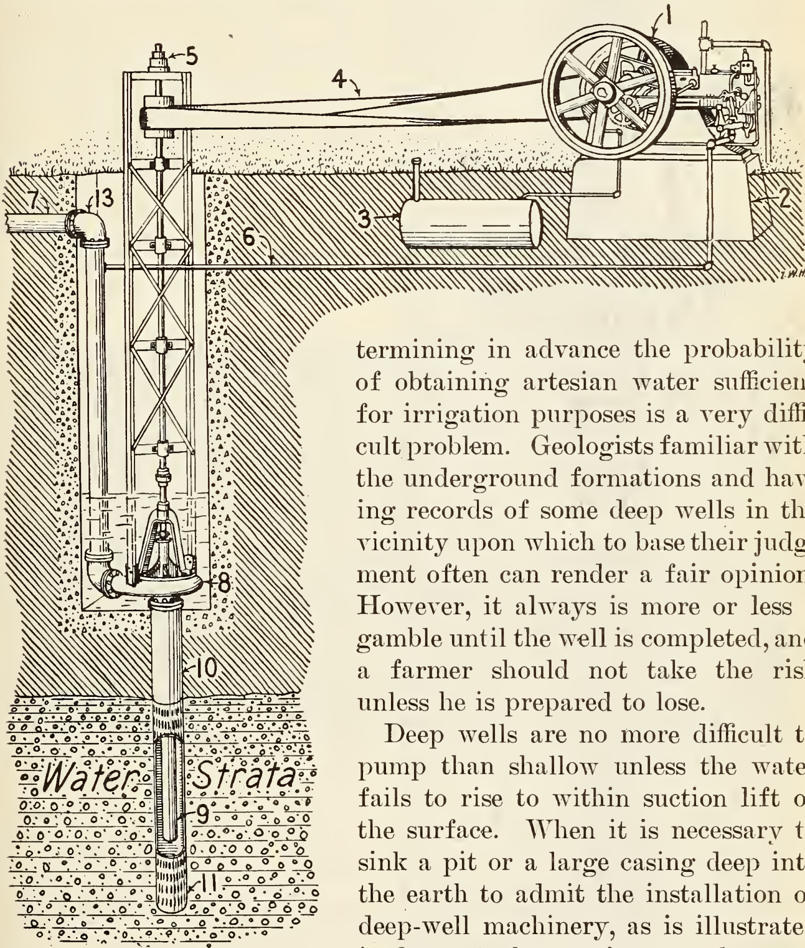

FIG. 5.—Typical installation of vertical-shaft centrifugal pump in pit with half-turn belt. Pump in this case is submerged in water. 1, Engine; 2, engine foundation; 3, fuel tank; 4, belt; 5, vertical shaft and bearings; 6, water-cooling pipe for engine; 7, discharge pipe; 8, pump; 9, suction pipe; 10, well casing; 11, well screen.

Deep wells are no more difficult to pump than shallow unless the water fails to rise to within suction lift of the surface. When it is necessary to sink a pit or a large casing deep into the earth to admit the installation of deep-well machinery, as is illustrated in figure 6, the cost is apt to be great and will be justified only where water can be obtained in sufficient amounts to irrigate a correspondingly large acreage.

Unlike water for drinking purposes, water for irrigation need not be pure from a bacterial standpoint. It is therefore allowable to draw on both waters near the surface and artesian supplies in the same well (fig. 6) by having the casing perforated or slotted wherever a good water-

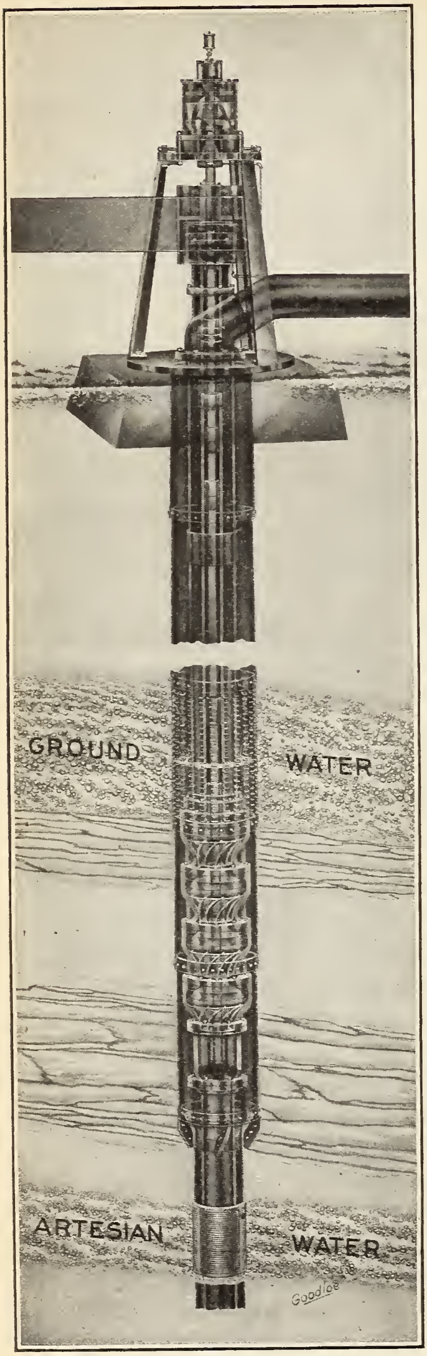

FIG. 6.—Deep-well pump in casing to permit installation of pump below ground-water level.

bearing stratum is intercepted. Care should be exercised to case off strata having a weak flow if strata having stronger flow are encountered in the same well, because water may be forced out of the well into the weak strata so that they will be a source of loss rather than gain. Each water-bearing stratum should be tested before the final casing is sunk, so that the well screens can be properly located and proportioned in size and mesh.

SCREENING WATER.

A difficult factor to control in many water supplies for spray irrigation is the clogging of nozzles and pipe lines by sediment, moss, lime, or other matter. This is true especially with the overhead system, where many small nozzles must be kept clean. The most desirable place to remove clogging matter is before the water enters the suction pipe of the pumping plant. Screens of different forms are placed in the "turning unions" at the feed end of each lateral, but these screens can remove only a small amount of material before they in turn must be cleaned. Sands from wells or other sources may be collected to a certain extent by placing in the main pipe line an enlarged chamber similar to a pressure tank, where the velocity is checked and the sand grains settle out. Under extreme conditions it may be necessary to reservoir well waters and repump after settling. Bucket-type screens for installation in mains are also obtainable. These screens can be removed conveniently from time to time and cleaned, to prevent undue resistance to the water.

Figure 7 illustrates a screen made for streams or other surface supplies. The screen is made on a 6-inch suction pipe for a capacity of 450 gallons per minute. Four 2-inch by 3-inch cypress staves 6 feet long are placed edgewise and equi-spaced against the shell of the pipe and allowed to extend 3 feet beyond the open end of the pipe. Two pieces of cypress 2 inches thick are used for ends, one being made with a hole to slip closely over the pipe and both spiked to the ends of the staves. Two half-inch iron rods with nuts on ends are run lengthwise through the structure with adequate strap-iron ties, so that the frame is clamped together. No. 9 galvanized wire is wrapped and stapled tightly about the staves, leaving spaces

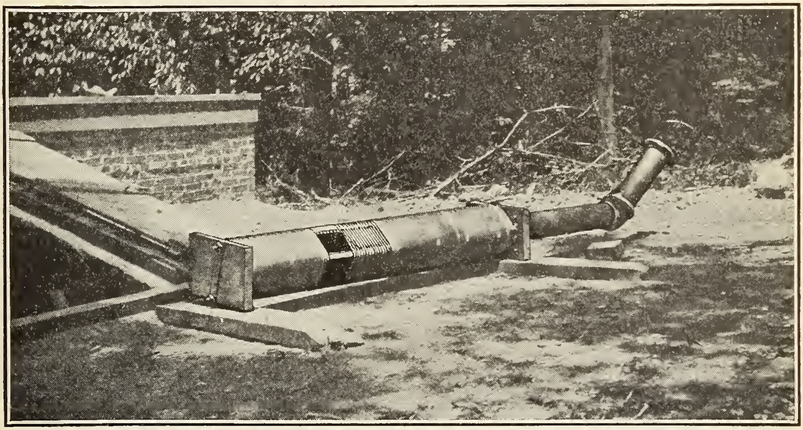

Fig. 7.—Perforated sheet-brass screen to be used in stream.

of about an inch between ribs. This forms a large wire tube 12 inches in diameter and 6 feet long, to which perforated sheet brass can be soldered and nailed. The sheet brass should have circular perforations no larger than the openings in the nozzles used in the spray system. The sheets can be purchased from sheet-metal dealers. The light portions of the picture show the joints soldered to the sheets and solder covering the nail head. The metal should be upset and nailed securely to the wooden ends of the screen.

The screen described above can be used in many cases suspended in a stream, where it can be brushed clean occasionally when the pump is not running. Care should be taken not to allow the first water pumped after cleaning to go into the spray system. In shallow streams containing very fine sediment or moss the screen should be laid horizontally in a concrete bulkhead or trench made in hardpan or rock below the bottom of the channel. The space built for the horizontal screen should be large enough so that coarse sand can be placed 12 inches thick on all sides and below the current of the stream. This bed can be covered with fine sand or burlap, thus forming a suction filter which can be occasionally cleaned by removing the top covering. The filter always should be covered with an auxiliary burlap or canvas, or the stream shut out when the plant is idle, so matter will not settle on the filter and be drawn in when the pump is started.

TYPES OF SPRAY IRRIGATION SYSTEMS.

Three types of spray irrigation construction have been adopted more or less widely for field irrigation. These are:

(1) Hose and movable-nozzle or movable lines fed from an underground pipe system and hydrant.

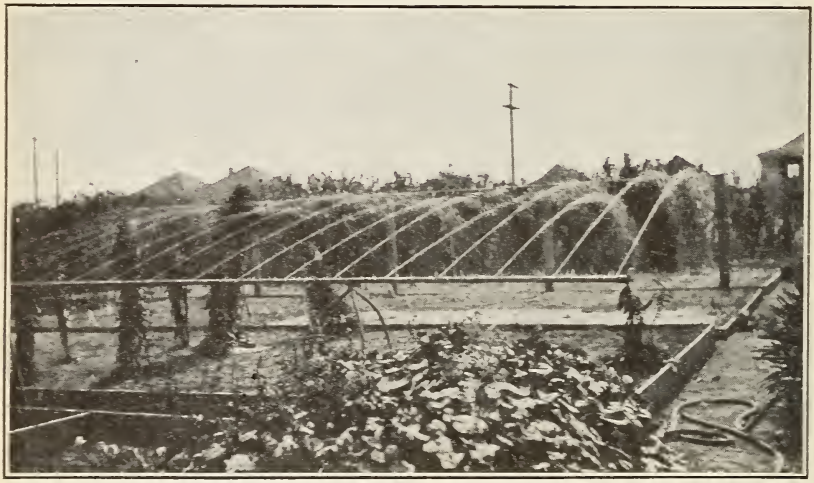

FIG. 8.—Portable spray equipment used in gardens about cold frames, hotbeds, etc. [Luther Burbank's gardens, Santa Rosa, Cal.]

(2) Circular nozzles fed from an underground pipe system.

(3) Overhead spray lines fed from an underground main feed pipe.

The hose and movable-nozzle type is used for the irrigation of cold-frame and hotbed crops, garden setting and seed beds, putting greens, public parks, lawns, small gardens, greenhouse plants, and in some Florida citrus groves. The feeder systems for this type consist of main pipe lines and branches which are laid underground to reach all portions of the field. At intervals of 50 to 200 feet, $\frac{3}{4}$ to $1\frac{1}{2}$ inch standpipes are brought to the surface and connections for hose made by means of shut-off valves threaded at the mouth for the hose unions. Lengths of rubber or canvas hose are used which will reach at least one-half the distance between standpipes, so that the entire area can be covered. There are many adjustable nozzles on the market which may be screwed to the end of a hose and made to discharge a solid stream or any degree of spray by manipulation of the nozzle parts. There are two familiar designs of nozzles for this purpose. One must be held in the hand constantly or moved about at very short intervals. The other may be set in one position and allowed to spray over a circular area.

One of the most popular portable spray arrangements is shown in figure 8. This consists of a ¾-inch pipe, 18 to 20 feet long, containing a row of small nozzles similar to those used in overhead irrigation systems. This pipe has a hose connection at one end and is supported on movable tripods or on short posts which are set permanently in the ground or attached to the cold frame or hot bed. In some instances the portable spray line contains three rows of " mist nozzles " set at about 45° angle with each other and 3 feet apart in the row. With this arrangement the pipe can be laid on top of a cold frame and a fine mist spray will cover the bed.

The hose and portable nozzle system of spray irrigation is the oldest and least efficient of spray methods. It is impossible to get an even application over the entire field or under one position of the nozzle. The constant attendance necessary and the liability of over or under irrigation makes the cost of operation high and the results dependent upon the skill of the laborer. The greatest field for this type of irrigation seems to be indoor spraying, outdoor sod lands, seed beds, and small garden plots. The first cost is the smallest of any type of spray irrigation.

STATIONARY-NOZZLE SPRAY SYSTEMS.

Stationary nozzles fed by underground pressure systems of piping (fig. 9) have gained favor in Florida, where the sandy character of the soils makes rapid irrigation necessary. This type of equipment is being used for the irrigation of truck and citrus groves. Standard steel or wrought-iron pipe and fixtures are commonly used, but the main feed pipe sometimes is cast iron or riveted steel. Main feed pipes are run underground, leading from the water works or pumping plant into the field. Laterals are placed 12 to 15 inches below the surface in parallel lines under the entire field. At intervals of 30 to 50 feet risers to which the nozzles are attached are placed on the lateral lines so that the nozzles are spaced equidistant from each other in triangular form, as shown in figure 9. Figure 10 shows an underground section of a main feed pipe, with connections to laterals. Each lateral is controlled by a valve and in some cases a valve is placed on each riser, so that a part of the nozzles on a line may be cut off, permitting the use of longer laterals of smaller pipe. The sizes of pipe must be so proportioned and the system so designed as to give as nearly as possible a uniform pressure on all the nozzles within the area to be irrigated at one time. The risers reach a height of 4 to 6

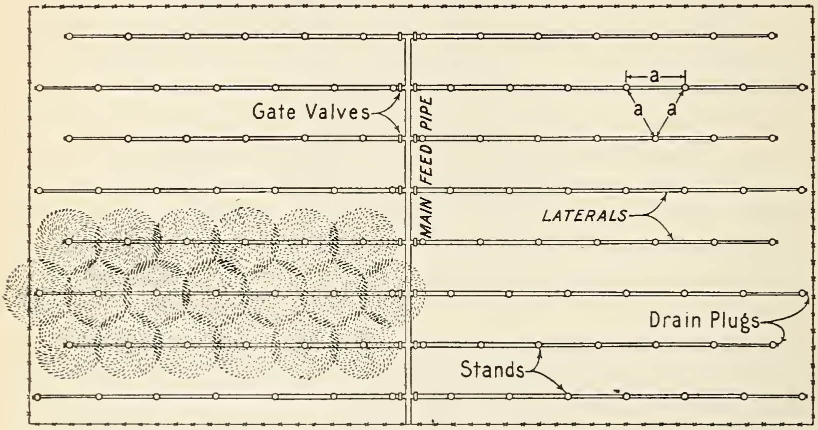

FIG. 9.—Typical plan for piping a field for stationary-nozzle spray systems, showing staggered positions of nozzles to obtain the least amount of overlapping of spray. Distances marked *a* should be equal.

feet above the surface for truck and extend above the trees for orchard irrigation and should be staggered, as shown in figure 9, to reduce the overlapping of spray.

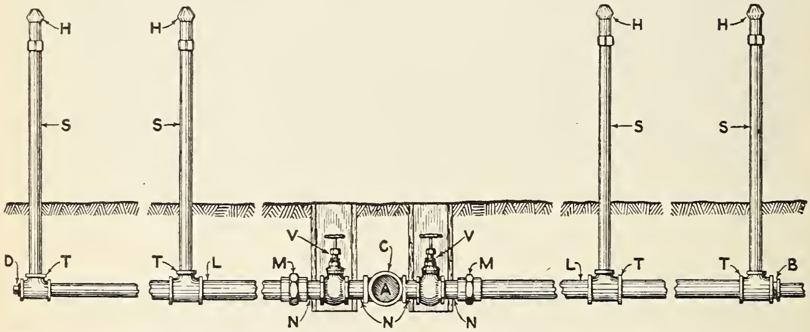

FIG. 10.—Sketch showing typical fittings of underground laterals for stationary-nozzle spray systems. *A*, Main feed pipe; *B*, bushing at reduction of pipe sizes; *C*, cross in main feed pipe; *D*, drain cock or plug; *H*, sprinkler heads or nozzles; *L*, lateral pipe lines; *M*, malleable unions; *N*, nipples; *S*, ¾-inch galvanized stand pipes; *T*, malleable tees; *V*, brass gate valves.

The nozzles vary in design and generally are made of brass. Those observed in the field by the writer may be classified in three groups (fig. 11). First, solid nozzles with no movable parts; second, adjustable nozzles with parts which can be manipulated to change their capacity or form of spray; third, rotary nozzles which have movable parts to assist in the distribution of water by centrifugal force or water power.

The efficiencies of nozzles found in use were determined by a series of tests made under the direction of this office in 1909 and the results are here summarized.

A popular solid nozzle (No. 4, fig. 11) was found to have a capacity of 1.93 cubic feet per minute (14.5 gallons per minute) under a pressure of 20 pounds per square inch, and it gave a fair lateral spread of 40 feet. Under 25 pounds pressure its capacity was 2.45 cubic feet per minute (18.4 gallons per minute) with a fair lateral spread of 42 feet. The zone receiving the greatest amount of water per square foot was found to be an annular ring about 15 feet from the nozzle. This ring received about 40 per cent more water per square foot than did the surface at 5 feet or 18 feet from the nozzle.

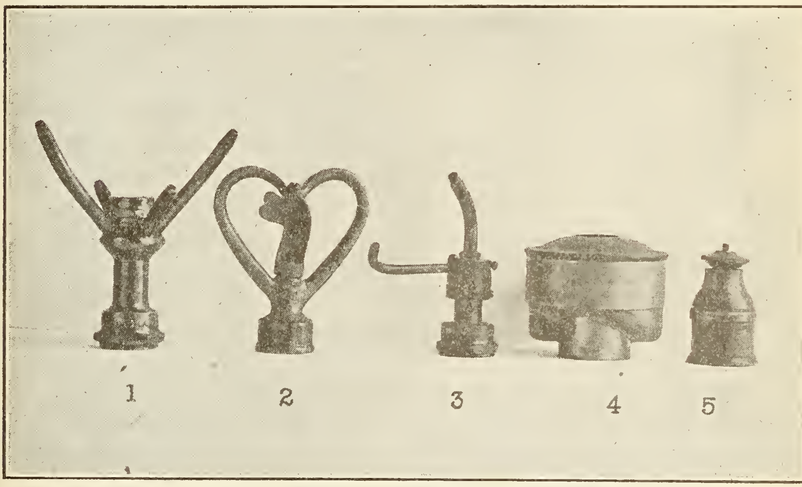

FIG. 11.—Types of circular-spray nozzles.

A popular adjustable nozzle (No. 5, fig. 11) was found to have a capacity of 0.98 cubic foot per minute (7.3 gallons per minute) under 20 pounds hydraulic pressure and a fair lateral spread of 35 feet. Under 25 pounds its capacity was 1.23 cubic feet (9.2 gallons) per minute and it gave a fair lateral spread of 38 feet. The nozzle was opened one-half turn during the above test, which gives a medium spray. A zone 12 feet from the nozzle received about 30 per cent more water per square foot than did the surface at 3 feet or 15 feet from the nozzle.

A popular rotary nozzle (No. 2, fig. 11) was found to have a capacity of 0.43 cubic foot (3.2 gallons) per minute under hydraulic pressure of 20 pounds, and it gave a fair lateral spread of 32 feet.

At 25 pounds pressure the capacity was 0.46 cubic foot (3.5 gallons) per minute with a fair lateral spread of 35 feet. The zone receiving the greatest amount of water was found to be a circular area 4 feet in diameter immediately about the nozzle. The amount received per square foot of area decreased uniformly with the distance from the nozzle.

The most striking results obtained from these tests and from similar tests with 7 other nozzles were the great ranges in capacities and the uneven distribution beneath individual nozzles. Every nozzle tested placed a large percentage of the total discharge on a small portion of the area it was supposed to irrigate. Solid and adjustable types placed the maximum amount in an annular ring having a radius about three-fourths that of the sprayed area. The rotary nozzles placed the maximum quantity of water close to the center and the quantity diminished rapidly with the distance from the nozzle.

The results of these tests, when considered in connection with the impossibility of fitting a set of circular areas together to cover a field without overlapping (fig. 9), bring out the difficulties in obtaining an even distribution of water with a stationary nozzle spray system. The cost of the system exceeds that of the hose and portable nozzle and in many cases that of the overhead equipment. The cost of operation is about the same as that of the overhead, but the efficiency and adaptability to the irrigation of delicate farm corps are generally less unless a larger amount of water is needed in a shorter time than the overhead system will supply. However, the stationary nozzles do not clog readily from rust or other particles present in many waters and operate on low pressures, which are advantages greatly in their favor, often sufficient for their adoption. This type of spray system often is considered more sightly than overhead types, while the operation is quite simple and automatic. Where it is desired to keep the cost low, block pipe can be used largely in the distribution system. The distribution is assisted greatly by a light breeze, but the field for this type of spray irrigation at present is largely confined to light soils that take water rapidly for the growing of crops and lawns that will stand a coarse spray.

STATIONARY OVERHEAD SPRAY SYSTEMS.

The development of a stationary overhead spray system marked the beginning of rapid progress in spray irrigation for commercial crops. The original overhead system consisted of a few lengths of steel pipe set on parallel rows of posts and connected to a hand force pump. A series of small holes was drilled in the shell of the pipe, through which water could be forced in the form of a spray. The holes gradually became clogged or irregular in shape, due to the rusting of the metal. The idea was conceived of replacing the holes with small brass nozzles which could be screwed into the pipe shell and would not rust. It was also found that by placing one row of nozzles in a pipe line which could be turned or rolled in bearings, a strip of land 50 feet wide could be irrigated by turning the line of nozzles to different positions through a total arc of about 90°. Special turning unions containing screens have been patented for connecting the nozzle lines to the feeder system. Likewise there are drilling machines for boring holes and tapping threads in the pipe for the nozzles. Machines for turning the nozzle lines backward and forward are being perfected and seem to be desirable for special conditions where night irrigation is practiced or spray is used for frost protection, as in Florida.

Figure 12 shows an underground section of a main feed pipe in the center of a field with connections to two nozzle lines, one on each side of a farm road, as in the typical farm (fig. 1).

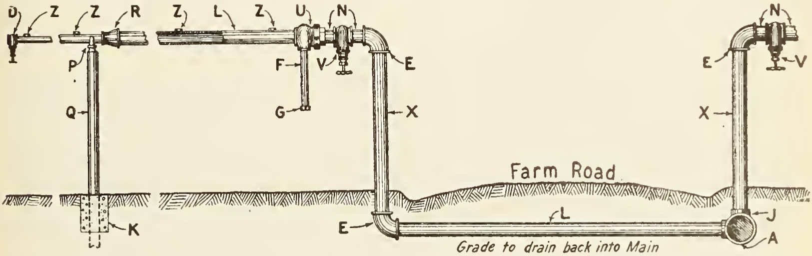

Fig. 12.—Sketch showing typical fittings for overhead nozzle lines connected to main feed pipe and method of crossing a farm road. *A*, Main feed pipe; *D*, drain cock or cap; *E*, elbow; *F*, handle for turning nozzle lines; *G*, cap on handle; *J*, side-outlet tee; *K*, concrete base for pipe post; *L*, nozzle-line pipe; *N*, "long" nipples; *P*, pipe hanger; *Q*, 1¼-inch pipe post; *R*, reducing cocket; *U*, turning union; *V*, brass gate valve; *X*, risers to nozzle lines; *Z*, nozzles.

LOCATION AND CONSTRUCTION OF OVERHEAD SPRAY SYSTEMS.

Each overhead spray plant should be modeled to fit the field and conditions under which it is to operate. Assuming that water supply has been developed, there are three major parts to any system which should be considered in the order given. First, type and location of nozzle lines; second, type and location of main feed pipe; third, type and location of pumping plant. The nozzle lines should take the direction most desirable to cultivate the field, so that the crop rows will be parallel to the rows of supports. In general, nozzle lines should run perpendicular to the main feed pipe. The entire field system should be designed to use the minimum amount of large pipe, which generally means to run the main as straight as possible, keeping the nozzle lines in sizes not to exceed 1½-inch pipe.

The sizes of pipe to use in a nozzle line depends upon the length. The end connecting with the feed pipe must be sufficiently large to carry the full head of water. As the water is diminished by each nozzle the pipe can be reduced in size, finishing with a ¾-inch pipe at the extreme end. The customary sizes of pipe used for the nozzles now on the market are set forth in Table 1.

TABLE 1.—*Sizes of pipe used for nozzles now on the market.*

	Total length of line.	¾-inch pipe.	1-inch pipe.	1¼-inch pipe.	1½-inch pipe.	2-inch pipe.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Nozzle No. 1, outdoor, 4 feet apart	150	150	...	...	...	...
	200	130	70	...	...	...
	250	100	150	...	...	...
	300	100	150	50	...	...
	400	90	160	150	...	...
	500	90	160	150	100	...
	600	90	160	175	175	...
	700	90	160	175	175	100
Nozzle No. 2, outdoor, 4 feet apart, or No. 1, 3 feet apart.	150	115	35	...	...	...
	200	100	100	...	...	...
	250	90	100	60	...	...
	300	90	100	110	...	...
	400	80	100	120	100	...
	500	75	100	120	120	85
	600	75	100	120	120	185

Nozzle lines are spaced such distances apart as will best fit the field within a range of 50 to 56 feet. The type of nozzle line depends principally upon the method used for supporting the pipe. The three popular methods are: On tall posts, on short posts, or on cables suspended from high posts.

TALL-POST TYPE.

When tall posts are used they are set in the ground 2½ to 3 feet and cut off about 6½ feet above the ground (fig. 13). These posts are spaced 15 to 20 feet apart and the nozzle line placed on the tops in roller bearings in the case of long lines and between nails in short lines. If the post is of wood it should be not lighter than 4 by 5 inches, but a round post 5 to 6 inches in diameter will serve as well. A more durable but expensive post can be made from a 1 or 1¼-inch steel pipe set in a base of concrete 6 inches in diameter and 2 feet deep (fig. 12). Special concrete posts also make excellent supports.

Where wooden posts are used it is advisable to treat the part going into the ground with a good grade of paint, tar, or creosote, to help preserve the wood. The treatment should extend 6 inches above the ground surface.

The tall posts permit the passing of horses or men under the pipe and obviate obstruction to cultivation. This is the most popular method and makes a good appearance when the posts are carefully lined and cut off at the tops so that the pipe will lie straight, or uniformly curved with the surface of the ground.

Short-Post Type.

If short posts are used they are set in the ground 2 to 2½ feet and cut off 1 to 3 feet above the surface. They are spaced 18 to 20 feet apart and the nozzle line placed on top between nails or in roller bearings. A 4 by 4 inch post serves well for this type, but should be treated as are tall posts. This construction is the least expensive, but may cause a somewhat closer spacing of nozzle lines if a low hydraulic pressure is to be used. This type also is somewhat in the way of cultivation and is not efficient for tall-growing crops. When nozzle lines are made portable on short posts, posts may be made of

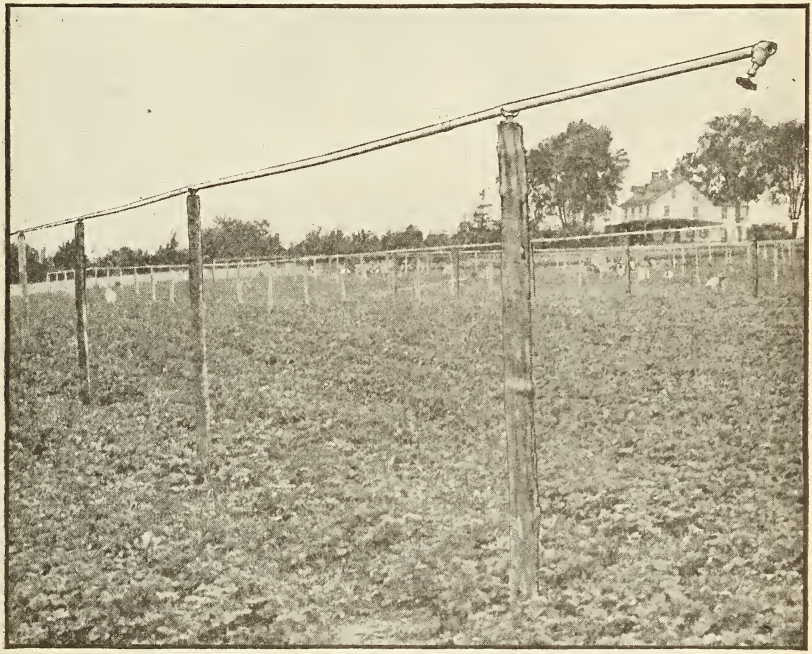

Fig. 13.—Overhead spray nozzle lines mounted on wooden posts 6½ feet above the ground. [Farm of Granville W. Leeds, Rancocas, N. J.]

¾-inch pipe sharpened and fastened to the nozzle line so that supports are moved with the pipe.

High Posts and Cable-Suspension Type.

Where high posts and cable suspension is used the posts are spaced from 100 to 200 feet apart and the nozzle line suspended from a tight cable or wire strand which takes the form of a catenary curve between posts (fig. 14). Telephone poles 8 to 10 inches at the base and 6 to 8 inches at the top can be used. A length of 2½-inch steel pipe which may be filled with concrete makes a more substantial post.

Wooden posts or black-steel posts should be painted with tar or treated with creosote. The posts should be considerably higher than the nozzle line, depending upon the distance between posts and the weight to be supported. It is well to set the bases of the posts in beds of concrete about 18 inches in diameter and 3 feet deep. The end posts and cables must be well anchored with guys fastened to wooden or concrete "deadmen." A 5-foot anchor rod should be attached to the deadman and extended above the surface with an eye where a turnbuckle and a guy wire can be attached, as shown in figure 15. Single guys are used where the tops of the end posts of several lines can be connected with a guy wire perpendicular to the nozzle lines, otherwise double guys should be used. The deadman

FIG. 14.—Overhead spray-nozzle lines suspended from high posts by cable line.

should be at least a distance equal to one-third the height of the post from the post's base.

The weight of cable to use for each particular case should be determined by an engineer familiar with this construction after he has been given the length of the line, the weight to be supported, and the spacing of posts. The manufacturers of cables are prepared to recommend necessary size and kind of cable. It is well to use double galvanized materials, which will be lasting. The pipe is suspended from the cable with short lengths of about No. 14 galvanized wire spaced 15 to 18 feet apart. The nozzle line is hung in special galvanized-metal hooks containing rollers to make the pipe turn easily, and an eye for attaching to the suspension wire. The nozzle line can be graded by adjusting the lengths of the suspension wires.

The chief advantage in the suspension system is the reduction of obstruction in the field, and where it is well constructed the plant will be very durable. This type costs more than the others and is not as commonly used as the simple post supports. The cleaning of nozzles on highly supported lines is difficult, so pipe should be kept within reach.

NOZZLE LINES.

The pipe in the nozzle lines should be galvanized wrought iron or steel. The galvanizing not only makes the system longer lived, but reduces oxidation of the metal, which, if not prevented, tends to form scales that fill the nozzles.

A nozzle line is connected with the main feed pipe by means of a riser cut the proper length to act as the first post in the line. In the longer lines it is well to have the riser of 1½-inch pipe, which will make a strong support even if this is larger than the first section of nozzle line. An elbow is placed on top of the riser, and into this is screwed a long nipple which terminates in a standard brass gate valve (fig. 12). To reduce friction this valve should be of the same size as the standpipe. The turning union is screwed into the opposite side of the valve. The union most commonly used contains a screen for catching sediment from the passing water. A capped handle 2 feet long, made of ¾-inch pipe, is screwed into the side of the union. This serves as a lever for turning the nozzle line in its bearing as well as giving entrance to the union for flushing the screen.

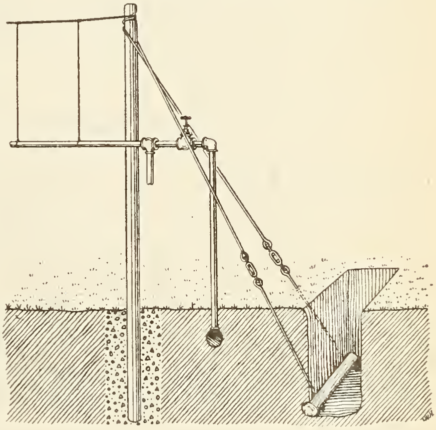

Fig. 15.—Anchorage for suspended overhead nozzle lines, showing location of "deadman" and turnbuckles.

Reducing couplings, and not bushings, should be used for connecting the different pipe sizes. A ¾-inch valve or a cap should be placed over the extreme end of the nozzle line. This permits flushing out the line at any time by opening the valve or removing the cap. (See fig. 13.)

Main Feed Pipes.

There are several kinds of pipe adaptable for spray irrigation mains—steel or wrought iron with threaded joints, riveted steel with flanged or bolted joints, cast iron with lead or bolted joints, and wood-stave pipe.

STEEL OR WROUGHT-IRON PIPE.

Steel or wrought-iron pipe with threaded joints which screw together, used for main pipe lines, is the common water or steam pipe used exclusively in all plumbing. This comes in random lengths of about 18 feet long and in all diameters. It is the best to use for mains up to 5 inches diameter. Larger sizes are expensive and more difficult to handle in the field. It is advisable to use galvanized-steel pipe throughout. However, black-iron fittings cost less than galvanized and outlast the galvanized pipe. Some irrigators prefer black "guaranteed" pure wrought-iron pipe for mains. This costs about the same as galvanized steel and is more durable than black steel. Pipe 2 inches and over in size should be cut, threaded, and marked to fit each section in the shop, as it is difficult and expensive to do this in the field. Where a main intersects a nozzle line a tee is used in the main and the standpipe for the nozzle line is screwed into the tee direct (fig. 12).

RIVETED STEEL PIPE.

Riveted steel pipe, made of sheet metal either straight or spiral-riveted into a pipe, can be purchased in sizes of 3-inch diameter and over. The thickness of metal used depends upon the pressure which the pipe must withstand and somewhat upon the length of life desired. The riveted pipe is treated with an asphalt-tar solution of mineral paint or is galvanized. The unprotected steel pipe never should be used in irrigation construction. The small sizes, from 3 to 8 inches, should be galvanized and the larger coated if not galvanized.

Riveted pipe can be made in any lengths convenient to handle in the field; 20 to 25 feet is the usual section. Two types of joints are used for riveted steel pipe, i. e., flange and gasket or bolted. The flanged joint is rigid and the line must be straight, unless the pipe is made curved in the shop. The bolted joint permits a small angle in the line at each joint, and generally is the most adaptable for irrigation mains. The bolted joints also act as expansion joints, which is advantageous in long lines. In all straight mains of great length some design of expansion joint must be used to care for expansion and contraction caused by changes in temperature.

Laterals or nozzle lines can be connected to riveted steel pipe mains by the use of a special tee. Where bolted joints are properly spaced in the mains the cast-iron collars of the joints can be tapped for the connections. It is also possible to have special flanges or saddles. into which the lateral can be screwed, riveted to the pipe in the shop.

Riveted steel pipe is more economical where large sizes are needed and long shipments must be made, as this pipe is light in weight.

It is easy to lay, but its comparative shortness of life is its chief disadvantage.

CAST-IRON PIPE.

Cast-iron pipe, such as is commonly used in city water systems, is adaptable for the larger installations of spray systems. Standard cast-iron pipe, 4 inches and larger in diameter, is made in 12-foot lengths. It is also made in two weights for 100 and 200-foot pressure heads. Usually the lighter weight is sufficient for spray irrigation systems, especially after the field is reached. Joints are made by pouring hot lead into the bell end of each section, or a bolted joint may be used. In some instances a rich mixture of cement mortar may be driven into the joint instead of lead. Connections for the laterals or nozzle lines are made with special fittings, or the shell of the pipe may be tapped and a saddle of metal or concrete placed around the connection.

The advantages of cast-iron pipe are its long life, comparative cheapness in the larger sizes where freight hauls are short, and ease of laying. The disadvantages are tendency to rust and scale after lying idle, heavy weight for long freight hauls, and need of special equipment for laying and tapping.

WOOD-STAVE PIPE.

Wood-stave pipe made of durable fir or redwood is used extensively for pressure conduits in the Western States. The pipe is built of carefully machined staves, which are held in place by metal bands. This pipe can be secured in sizes 2 inches in diameter and larger. The smaller sizes usually are made in sections and joined together by means of a collar or sleeve. Large sizes may be built continuously in the field. Connections for laterals are made easily by metal saddles. The metal bands should be heavily galvanized and the wood treated with a preservative. The advantages of wood pipe are its comparative cheapness in first cost and smoothness of bore. Provision should be made to keep the pipe full of water, otherwise the staves will dry and decay.

TYPES OF PUMPS FOR SPRAY IRRIGATION.

All spray irrigation plants require power pumping equipment unless pressure can be supplied from an elevated source or municipal water works. To generate a spray requires a high-pressure pump producing 25 to 40 pounds pressure on the nozzles in addition to elevating the water to the field. The two types of pumps used for this purpose may be classified under "displacement" and "centrifugal" pumps.

Displacement pumps are those which force water by means of a piston or plunger traveling backward and forward in a close-fitting cylinder. Centrifugal pumps are those which force water by means of an impeller or fanned wheel revolving at a high speed in a close-fitting shell or case.

DISPLACEMENT PUMPS.

Displacement pumps are divided into groups according to the number of cylinders they contain, while each group can be subdivided into single-acting or double-acting pumps, depending on whether the water is forced during the forward stroke only or during both the backward and forward strokes of the piston. For spray irrigation one and two cylinders should be double-acting. Three cylinders should be single-acting.

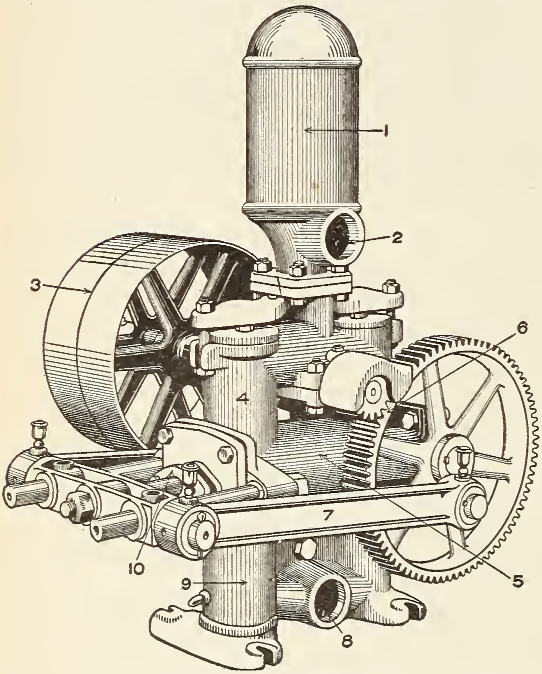

FIG. 16.—Typical simplex, double-acting displacement pump. 1, Air chamber; 2, discharge opening; 3, tight and loose pulleys; 4, valve chamber; 5, cylinder; 6, gear; 7, connecting rod; 8, suction opening; 9, base; 10, packing gland.

A typical one-cylinder or simplex pump is shown in figure 16, with its principal parts numbered and named. These pumps are adapted for spray systems requiring up to 114 gallons per minute, and will work against a total head of 175 feet. This type of pump is adapted to small plants where the water can be obtained within suction lift, and may be installed on the surface or in a pit, and driven by belt or gear connection to power. Single-cylinder double-acting pumps are adapted also to deep-well pumping where the cylinder is suspended in the well and operated from the surface by a power working head, of which figure 17 is a typical design for small plants.

Duplex or two-cylinder pumps usually are constructed with two cylinders lying horizontally on a common base, which also holds a power working head. The duplex pumps are adapted to large plants for pumping from surface supplies to any height. They can be driven by either belt or gear connection to the power.

Triplex or three-cylinder pumps are adapted for pumping water from surface supplies to any height of lift for the larger plants. For special well conditions triplex pumps are designed for the three cylinders to work in a pit while the power working head remains on the surface. These also can be driven by belt or gear connection to the power.

Small displacement pumps of the belt-driven types should be equipped always with tight and loose pulleys to aid in starting the engine. For the same reason large outfits should be equipped with friction-clutch pulleys on the shaft if belt driven and shaft clutches if gear connected. Clutches are not so essential where electric power is used for either small or large plants. All displacement pumps should be equipped with ample air chambers to act as cushions in absorbing the pulsations of the water. Relief valves or by-passes should be placed in the discharge pipes to prevent breaking the pumps or engines should all or a part of the spray lines be shut off.

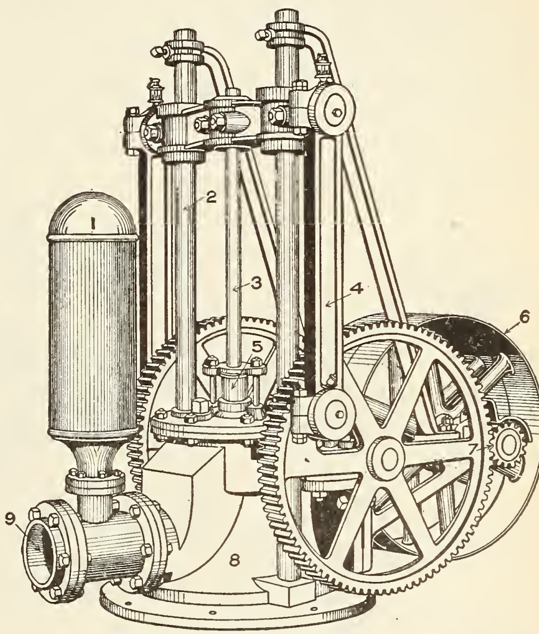

FIG. 17.—Typical power working-head for deep-well pumps having a 24-inch stroke. 1, Air chamber; 2, crosshead guides; 3, piston rod; 4, connecting rod; 5, packing gland; 6, tight and loose pulleys; 7, gear wheel; 8, base; 9, discharge opening.

CENTRIFUGAL PUMPS.

Centrifugal pumps can be classified as volute and turbine types. Each type can be divided further into pumps having one, two, etc., stages, according to the number of impellers contained. Figure 18 shows a typical single-stage volute-type pump with exposed impeller. Single-stage pumps are built in both volute and turbine types for any lift practical for spray irrigation; however, the possible lift depends greatly upon the speed of the impeller, which usually makes it desirable to adopt a two-stage pump when the lift exceeds 100 to 150 feet, which can be run at practically one-half the speed of a single stage. Figure 19 shows a typical two-stage turbine pump with a split shell which allows easy access to the impeller and bearings. The volute type usually is cheaper in first cost than the turbine, but the latter is more efficient.

Centrifugal pumps can be used for spray irrigation to lift water from surface supplies (fig. 2), shallow wells (fig. 4), or deep wells (fig. 6). The pumps are built with horizontal shafts, as shown in figures 18 and 19, and with vertical shafts, as shown in figures 5 and 6. Centrifugal pumps may be driven by belt connection to the power or, where electric power is available, the motor can be connected direct, as shown in figure 18.

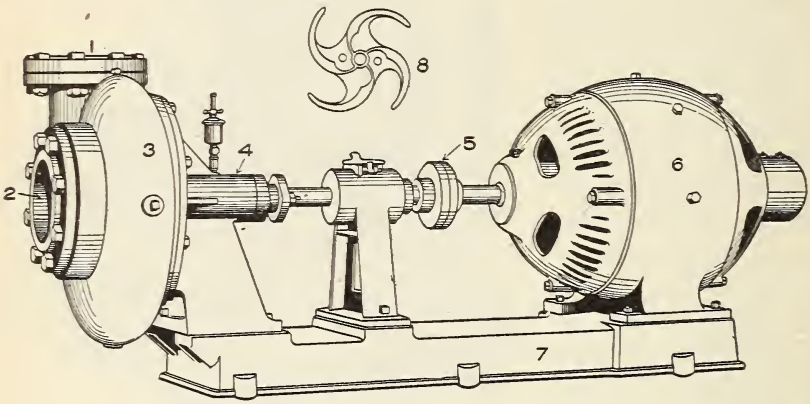

FIG. 18.—Single-stage centrifugal pump direct connected to electric motor, showing an open-type impeller. 1, Discharge; 2, suction; 3, pump volute or case; 4, stuffing box; 5, coupling; 6, electric motor; 7, base; 8, impeller.

The chief advantages of centrifugal pumps compared with displacement for spray irrigation are their low first cost for the same capacity, their simplicity, and the few wearing parts. A centrifugal pump also fits itself readily to pressure changes of a spray system without the use of a by-pass or relief valve. One spray line or all may be shut off to suit the needs of the farmer while the pumping plant is running, without ill effects to the machinery.

Centrifugal pumps must have a free suction intake and usually should not be attached directly to well casings, but should have a separate suction pipe extending into the water well below suction lift. All centrifugal pumps must be full of water before they will draw through the suction. All air should be excluded from the suction pipe and pump case before starting. A common method is to pump the air out with an ordinary hand pump, which causes the water to rise in the suction pipe and fill the pump. The hand pump must be a vacuum pump when placed above suction lift of the water level (see Table 5). In this case an air-tight check valve is placed in the discharge pipe just above the centrifugal pump to prevent air entering through the discharge pipe. The smaller centrifugal pumps can be purchased with a "hand primer" built into the suction and are adapted to low suction lifts. Figures 5 and 6 show centrifugal pumps submerged in water, so that the case is always full and needs no priming. Figure 2 illustrates how the pump can be primed from a barrel or any elevated source. In this case it is necessary to have a check valve or foot valve in the suction pipe below the water level to prevent the priming water from running out through the suction

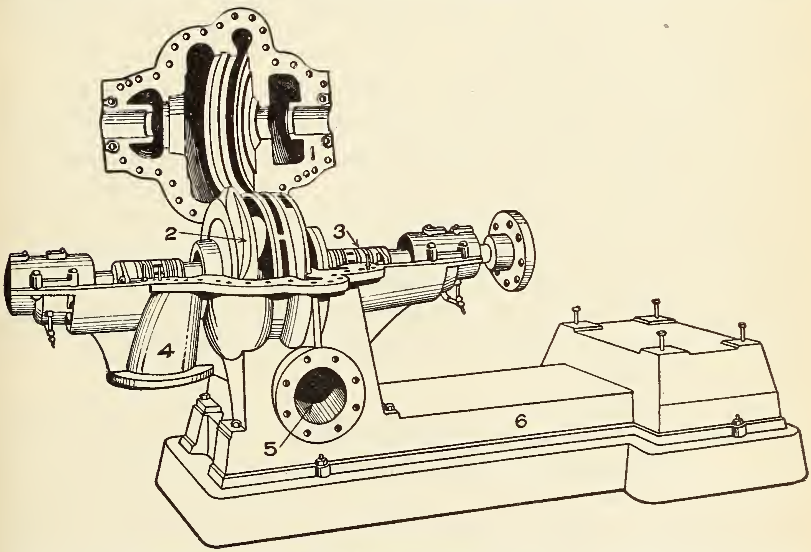

FIG. 19.—Typical two-stage split-case centrifugal pump. 1, Top half of split case, raised; 2, impellers; 3, packing; 4, suction; 5, discharge; 6, base.

pipe. A check valve is preferable to a foot valve because of the ease in entering and less resistance to the water. When the pump is started the priming barrel will be refilled if the valve is left open for a short time.

THE DESIGNING OF SPRAY IRRIGATION SYSTEMS.

Every spray irrigation system can be divided into three parts, which must be considered in their proper relation to each other in the design of a plant. First, the distribution-pipe system, which applies the water directly to the crops through some type of nozzle; second, the main feed pipe, which conveys the water from the source to the distributaries; third, the pumping equipment, which lifts the water and develops the pressure, unless the water and pressure are obtained from a gravity or municipal supply.

The distribution system should be laid out to use the minimum amount of large pipe for both distributaries and main feed pipe. The laterals or nozzle lines should run in a direction which will give the least amount of obstruction to the cultivation of the field in the most efficient manner. The field should be laid off in irrigation blocks or units, a unit representing the area to be irrigated at one time. The unit should be of a desirable length for the kind of crops to be irrigated. Where possible, it is advisable to divide the field by the irrigation system into blocks which will make the estimating of acreages easy when arriving at the amount of seed and fertilizer required or determining yields. This is done usually by having a convenient fraction of an acre under each spray line or by having the crop rows a length which will make each rod or yard in width a known fraction of an acre.

To keep the cost of a spray distribution system as low as possible, yet obtain a good uniform pressure and distribution of water, the sizes of pipes must be proportioned properly. Each lateral or nozzle line must be proportioned in size according to the number and capacity of the nozzles used. The main feed pipe must be proportioned to carry the total amount of water to the most distant irrigation unit and then be reduced in size as the water is decreased by each nozzle line within the irrigation unit. The water required to run an irrigation unit determines the capacity of the pumping equipment.

There is a resistance to water flowing in pipe which has been determined by experiments and is called "friction head." This friction is in proportion to the roughness of the inside surface of the pipe and varies with the velocity of the water and the length and diameter of the pipe line. The greater the friction of the water in the pipe the more power is required to pump the water; therefore, there is a logical size of pipe to use for each quantity of water and set of conditions to keep this frictional factor within reasonable limits. Table 2 shows the quantities of water which should be carried in different sizes of iron pipe.

TABLE 2.—*Amount of water different sizes of straight iron pipe will carry without excessive friction for spray irrigation.*

Diameter of pipe.	Quantity per minute.	Diameter of pipe.	Quantity per minute.
	Gallons.		*Gallons.*
½ inch	1 to 2	3 inches	75 to 125
¾ inch	3 to 4	3½ inches	125 to 175
1 inch	5 to 8	4 inches	175 to 250
1¼ inches	9 to 16	5 inches	250 to 400
1½ inches	17 to 25	6 inches	400 to 600
2 inches	25 to 45	7 inches	600 to 900
2½ inches	45 to 75	8 inches	900 to 1,200

Table 3 shows the number of feet which should be added to the lift for each 100 feet of straight pipe to overcome the friction and to obtain the total lift which must be pumped against. Tables 2 and 3 should be used by the farmer for estimating purposes, while the proportioning of the pipe sizes in the final design should be done by an irrigation engineer or by the manufacturers of the spray equipment used.

TABLE 3.—*Number of feet to be added to the vertical lift for each 100 feet of common iron pipe to overcome "friction head."*

[Based on Williams-Hazen formula, using a coefficient of 100.]

Gallons per minute.	Size of pipe.												
	¾-inch.	1-inch.	1¼-inch.	1½-inch.	2-inch.	2½-inch.	3-inch.	3½-inch.	4-inch.	5-inch.	6-inch.	7-inch.	8-inch.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
5	10.5	3.25	0.84										
6	14.7	4.55	1.20										
8	25.0	7.80	1.59	0.95									
10	38.0	11.70	2.05	1.43	0.50								
12		16.40	4.30	2.01	.70								
14		22.00	5.70	2.68	.94	0.32							
16			7.30	3.41	1.20	.41							
18			9.10	4.24	1.49	.50							
20			11.10	5.20	1.82	.61	0.25						
25			16.60	7.80	2.73	.92	.38						
30			23.50	11.00	3.84	1.29	.54						
35				14.7	5.10	1.72	.71	0.32					
40				18.8	6.60	2.20	.91	.41					
45				23.2	8.2	2.76	1.15	.51					
50					9.9	3.32	1.38	.62	0.34				
60					13.9	4.65	1.92	.89	.47				
70					18.4	6.20	2.57	1.11	.63	0.21			
80					23.7	7.90	3.28	1.46	.81	.27			
90						9.80	4.08	1.80	1.00	.34			
100						12.00	4.96	2.22	1.22	.41			
120						16.80	7.00	3.10	1.71	.58	0.23		
140						22.30	9.2	4.20	2.28	.76	.30		
160							11.8	5.25	2.91	.98	.36		
180							14.8	6.30	3.61	1.22	.47		
200							17.8	7.7	4.40	1.48	.56	0.28	
220							21.3	9.6	5.2	1.77	.69	.33	
240								11.6	6.2	2.08	.83	.39	0.22
260								13.3	7.2	2.41	.95	.47	.25
280								15.2	8.2	2.77	1.10	.53	.28
300								17.8	9.3	3.14	1.26	.62	.33
350								22.6	12.90	4.19	1.68	.82	.45
400									16.0	5.40	2.10	1.03	.56
450									19.8	6.70	2.52	1.24	.71
500									24.0	8.10	3.15	1.50	.84
550										9.6	3.70	1.81	1.01
600										11.3	4.35	2.18	1.20
650										13.2	4.90	2.50	1.40
700										15.1	5.80	2.90	1.60
750										17.2	6.60	3.30	1.78
800										19.4	7.50	3.65	2.00
850										21.7	8.40	4.20	2.26
900											9.20	4.50	2.50
950											10.1	5.10	2.80
1,000												5.60	3.10

Table 4 is a bill of materials for the typical farm (fig. 1, p. 4), and is given as an example of a form for obtaining quotations on spray irrigation equipment (see also fig. 12, p. 19). "Run" means a certain amount of pipe which will give a desired length when screwed together. Pipe less than 2 inches in diameter can be cut in the field, hence the actual number of feet required is stated for such pipe. "Location" refers to the location in the field. Nozzle lines are assumed to be 630 feet long on each side of the farm road. Pipe posts are assumed to be set 18 feet apart, and 9 feet long, to support nozzle lines 6½ feet above the surface.

TABLE 4.—*Bill of materials.*

Amount.	Size.	Item.	Location.
	Inches.		
1 run, 410 feet	6	Black guaranteed wrought-iron pipe, cut to exact length, with allowance for 1 tee in each run.	Main feed pipe.
12 runs, 50 feet each	6	.....do	Do.
1 run, 25 feet	6	.....do	Do.
20 runs, 30 feet each	2	Galvanized wrought-steel pipe	Feed end east-and-west nozzle lines.
20 pieces, 7 feet each	2	.....do	Nozzle-line risers.
7 pieces, 15 feet each	2	.....do	Pipe under road, east-and-west lines.
3,500 feet	1½	.....do	Do.
3,500 feet	1¼	.....do	Do.
3,200 feet	1	.....do	Do.
1,800 feet	¾	.....do	Far end all nozzle lines.
700 pieces, 9 feet each	1¼	Galvanized wrought-steel pipe, plain ends.	Pipe posts.
7	6 by 2 by 2	Black side outlet cast-iron tees	Main feed pipe.
6	6 by 2	Black cast-iron tees	Do.
7	2	Black malleable 90 ells	Bottom west risers.
20	2	Galvanized malleable 90 ells	Top east-and-west risers.
20	2	Galvanized long nipples	Feed end nozzle lines.
20	2 by 1½	Galvanized reducing sockets	Nozzle lines
20	1½ by 1¼	.....do	Do.
20	1¼ by 1	.....do	Do.
20	1 by ¾	.....do	Do.
20	2	Standard brass gate valves	Feed end nozzle lines.
20	¾	.....do	Far end nozzle lines.
1	6	Standard iron-body gate valve	End of main.
20	2	Trade name, etc., turning unions	Nozzle lines.
3,160	No. —.	Trade name, etc., nozzles	Do.
700	No. —.	Trade name, etc., galvanized hangers.	Top of posts.

NOTE.—Main feed pipe is made 6-inch size full length, as full head of water is to be pumped to farther fields for surface irrigation.

THE DESIGNING OF PUMPING PLANT.

As in the designing of the field system, the farmer should obtain all possible assistance in designing a suitable pumping equipment. It is desirable to purchase machinery for which repairs can be obtained readily from a local representative, yet when the services of an irrigation engineer are not obtainable the farmer should submit all possible data regarding the conditions the plant must fill to several reliable pump manufacturers for recommendations and quotations. A suitable request for the pump alone or a complete outfit including engine or motor for this purpose may be submitted in the following form:

GENTLEMEN:

You are requested to submit recommendations and bids on pumping equipment for spray irrigation purposes to fill the conditions outlined below. Prices should be quoted on (pump, engine, motor) delivered at ____________________ (nearest railroad station), accompanied by full descriptions of items it is proposed to furnish, stating guaranties, efficiencies, and making recommendations on the size and items of construction for suction and discharge pipes to be used.

The source of water supply is ---------- (well, creek, etc.).

The capacity of the water supply is ------ gallons per minute.

The foundations for pump and engine are to be of ---------- (concrete, brick, wood) set in ---------- (clay, loam, sand, rock) type of soil.

The vertical distance of water below proposed pump foundation is ------ feet.

The vertical distance water will draw down when pump is running is ------ feet.

The horizontal distance of water from proposed pump is ----------.

The vertical distance of proposed pump foundation from highest land to be irrigated is ----------.

The horizontal distance of proposed pump from the most distant irrigation unit is ----------.

The suction of pump must be ---------- (vertical or horizontal).

The discharge of pump must be ---------- (vertical or horizontal).

The number of bends in suction pipe must be ---------- of ---------- (90 or 45) degrees angle.

The number of bends in discharge pipe must be ---------- of ---------- (90 or 45) degrees.

The amount of water desired per minute is ----------.

The desired pressure on nozzles for the highest ground is ----------.

The height of nozzles above highest ground will be ----------.

The type of pump preferred is ---------- (displacement, centrifugal), to be connected to power by ---------- (belt, gear, direct).

The power desired for operating the pump is ----------.

I now have a ------ horsepower ---------- engine.

The speed of my engine is ------ revolutions per minute.

The size of engine belt pulley is ---------- diameter, ---------- width.

I can obtain alternating electric current of ---------- phase, ---------- cycles, ---------- voltage.

I can obtain direct electric current of ---------- voltage.

The following is a sketch of my water supply, showing the desired location of pumping plant and field to be irrigated.

SUCTION LIFT.

It is advisable to set all pumps as close to the water as possible and under ordinary conditions the suction lift should not exceed that given in Table 5. Suction depends upon the atmospheric pressure, which decreases as altitude increases.

TABLE 5.—*Practical suction lift of pumps at different altitudes.*

Altitude above sea level.	Practical suction lift of pumps.[1]	Altitude above sea level.	Practical suction lift of pumps.[1]
	Feet.		*Feet.*
Sea level	25	1 mile (5,280 feet)	20
¼ mile (1,320 feet)	24	1¼ miles (6,600 feet)	19
½ mile (2,640 feet)	23	1½ miles (7,920 feet)	18
¾ mile (3,960 feet)	21	2 miles (10,560 feet)	17

[1] Practical suction lift of pumps is equal to the vertical distance water is lifted, plus the head due to friction.

POWER.

The kind and amount of power a farmer should use for spray irrigation must depend much upon his local facilities for obtaining fuel or electricity. The fuels most commonly used in the humid regions are gasoline, kerosene, natural gas, and, in Florida, wood. In the arid regions the heavier oils, as well as electricity, are more available and can be added to the other common sources of power. With an engine a farmer is incurring no fuel charge except when it runs, although where a plant is to be run more or less continuously during an irrigation season, as in the arid districts, electricity is a much more automatic, cleaner, and often cheaper power to use. Some farmers may have a portable engine or tractor for other uses on the farm which can be used economically if the pump is purchased to suit such power.

TABLE 6.—*Horsepower required to lift different quantities of water to elevations of 10 feet to 300 feet.*

[Efficiency of pumping plant, 50 per cent of theoretical. Use for estimating purposes only.]

Gallons per minute.	Elevation in feet.															
	10	20	30	40	50	60	70	80	90	100	125	150	175	200	250	300
	h.p.	*h.p.*	*h.p.*	*h.p.*	*h.p.*	*h.p.*	*h.p.*	*h.p.*	*h.p.*	*h.p.*	*h.p.*	*h.p.*	*h.p.*	*h.p.*	*h.p.*	*h.p.*
5	0.025	0.05	0.07	0.10	0.12	0.14	0.16	0.20	0.22	0.25	0.31	0.37	0.43	0.50	0.62	0.75
10	.050	.10	.15	.20	.25	.30	.35	.40	.44	.50	.62	.75	.87	1.00	1.24	1.50
15	.075	.15	.22	.30	.37	.45	.52	.60	.68	.75	.94	1.12	1.31	1.50	1.88	2.25
20	.100	.20	.30	.40	.50	.60	.70	.80	.90	1.00	1.25	1.50	1.75	2.00	2.50	3.00
25	.125	.25	.37	.50	.62	.75	.88	1.00	1.12	1.25	1.56	1.87	2.18	2.50	3.12	3.75
30	.150	.30	.45	.60	.75	.90	1.04	1.20	1.35	1.50	1.87	2.25	2.62	3.00	3.74	4.50
35	.175	.35	.52	.70	.87	1.05	1.22	1.40	1.58	1.75	2.19	2.62	3.15	3.50	4.38	5.25
40	.200	.40	.60	.80	1.00	1.20	1.40	1.60	1.80	2.00	2.50	3.00	3.50	4.00	5.00	6.00
45	.225	.45	.67	.90	1.12	1.35	1.56	1.80	2.02	2.25	2.81	3.37	3.94	4.50	5.62	6.75
50	.250	.50	.75	1.00	1.25	1.50	1.74	2.00	2.24	2.50	3.12	3.75	4.37	5.00	6.24	7.50
60	.300	.60	.90	1.20	1.50	1.80	2.10	2.40	2.70	3.00	3.75	4.50	5.25	6.00	7.50	9.00
70	.350	.70	1.05	1.40	1.75	2.10	2.44	2.80	3.14	3.50	4.38	5.25	6.12	7.00	8.76	10.50
80	.400	.80	1.20	1.60	2.00	2.40	2.80	3.20	3.60	4.00	5.00	6.00	7.00	8.00	10.00	12.00
90	.450	.90	1.35	1.80	2.25	2.70	3.14	3.60	4.04	4.50	5.62	6.75	7.87	9.00	11.24	13.50
100	.500	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	6.25	7.50	8.75	10.00	12.50	15.00
125	.625	1.25	1.87	2.50	3.12	3.75	4.36	5.00	5.62	6.25	7.81	9.37	10.94	12.50	15.62	18.75
150	.750	1.50	2.25	3.00	3.75	4.50	5.24	6.00	6.75	7.50	9.37	11.25	13.12	15.00	18.74	22.50
175	.875	1.75	2.62	3.50	4.37	5.25	6.12	7.00	7.88	8.75	10.94	13.12	15.31	17.50	21.88	26.25
200	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	12.50	15.00	17.50	20.00	25.00	30.00
250	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50	15.62	18.75	21.87	25.00	31.24	37.50
300	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	18.75	22.50	26.25	30.00	37.50	45.00
350	1.75	3.50	5.25	7.00	8.75	10.50	12.25	14.00	15.75	17.50	21.87	26.25	30.62	35.00	43.74	52.50
400	2.00	4.00	6.10	8.00	10.00	12.00	14.00	16.00	18.00	20.00	25.00	30.00	35.00	40.00	50.00	60.00
450	2.25	4.50	6.75	9.00	11.25	13.50	15.75	18.00	20.25	22.50	28.13	33.75	39.37	45.00	56.26	67.50
500	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	31.25	37.50	43.75	50.00	62.50	75.00
600	3.00	6.00	9.00	12.00	15.00	18.00	21.00	24.00	27.00	30.00	37.50	45.00	52.50	60.00	75.00	90.00
700	3.50	7.00	10.50	14.00	17.50	21.00	24.50	28.00	31.50	35.00	43.75	52.50	61.25	70.00	87.50	105.00
800	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00	50.00	60.00	70.00	80.00	100.00	120.00
900	4.50	9.00	13.50	18.00	22.50	27.00	31.50	36.00	40.50	45.00	56.25	67.50	78.75	90.00	112.50	135.00
1,000	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	62.50	75.00	87.50	100.00	125.00	150.00

Table 6 gives the power necessary to lift different quantities of water different heights. The table is based on an efficiency of 50 per cent of the theoretical horsepower, and will serve the farmer for general estimating purposes. Small plants under 100 gallons per minute, especially in the case of centrifugal pumps, are apt to require a greater horsepower than given, while the larger plants should require somewhat less, due to the greater efficiencies. In every case, however, the actual horsepower to use should be determined by the manufacturers furnishing the pump.

OUTLINE OF PROCEDURE FOR INSTALLING SPRAY IRRIGATION SYSTEMS.

This outline is for the installation of an overhead spray plant, but by substituting underground laterals and nozzle risers for nozzle lines and posts it will apply to the stationary, circular nozzle type of system.

First, excavate a trench for the main feed pipe. Second, lay the main feed pipe. Third, screw nozzle line risers into main feed pipe. Fourth, install posts for nozzle lines. Fifth, assemble and tap nozzle lines for nozzles. Sixth, install pumping equipment and house. Seventh, pump water thorugh distribution system to flush out dirt. Eighth, install nozzles in nozzle lines.

INSTALLING THE MAIN FEED PIPE.

The main feed pipes are expensive items and therefore should be carefully designed and located. Usually the main pipes should be made as short as possible and yet intersect the nozzle lines at intervals so that their length will not exceed 600 feet; otherwise the sizes of the nozzle lines become large enough to offset any saving in cost from the use of fewer mains. The field to be irrigated should be divided into irrigation units, each unit having an area to correspond to the capacity of the main and pumping plant. The main feed pipe should be given sufficient size to carry the water for one unit at a time without excessive friction loss. (See Table 2, p. 30.) When the most distant unit is reached the main can be decreased in size gradually to correspond to the amount of water taken out by each nozzle line, unless the full capacity is needed for extension or another type of irrigation in an adjoining field. All pipe over 2 inches in diameter should be cut in the shop to fit the spacing of nozzle lines. Straight mains of the larger sizes should be equipped with expansion joints near the pumps to absorb the contraction and expansion of the pipe due to changes of temperature. Easy bends should be used where it is necessary to change the course of the main. All angles retard the flow of water by friction.

The main feed pipe should be laid underground below the depth of cultivation and on a grade so it can be drained at convenient places, especially in regions where freezing occurs. The main should be installed as the first part of the construction so that the posts for the nozzle lines can be set to correspond with the risers from the main.

Excavating for the main can be facilitated by plowing and throwing the loose materials out by hand. The second and following plowings should be done with a narrow plow hitched to a steady horse. The main pipe should be put together while lying on timbers across the trench, so that each joint can be fitted easily and tightened. Usually a section of 200 feet or more can be put together and then allowed to sag gradually into the trench as the length increases. There are two points where installation of a main feed pipe may begin. If the pumping plant has been installed and careful measurement has been made to the first lateral, the main can begin at the pump. If there is an important branching of mains, then the starting point can be at the branch or the first definitely located nozzle line nearest the pump and the pipe then laid in two directions toward the pump and through the field. The main pipe then can be cut to fit to the pump or the pump set to fit the main with the aid of the expansion joint and flange couplings.

INSTALLING NOZZLE LINES.

The first parts of the field system to be installed are the posts. These should be located carefully to line up in every direction, so far as possible, like trees in an orchard. The risers from the main feed pipe should form the first post to each line and form a starting point for measuring. It usually is advisable to locate the posts on the two outside lines of the field and then one center line in which the posts will line up with the outside ones. It is an easy matter then to locate the remainder of the posts by intersection sighting. In the case of wooden posts, the tops should be cut to uniform heights. Posts made from pipe can be driven a short distance into the earth in the bottom of a post-auger hole, and after they are lined up and adjusted to a uniform height the auger hole about the pipe can be filled with concrete.

After the posts have been set in the field the bearings are fastened to them and the sections of pipe placed on the ground along the side of each line. Each nozzle line is then screwed together tightly, great care being taken to remove all dirt and filings from each section. Paint or lead should not be used on the inside of the joints, as such material on the inside would cause clogging of the nozzles. It is better to apply heavy graphite grease after the thread has been started. When wooden posts are used, the pipe line is laid upon 60 to 90-penny spikes, one of which is driven firmly into the side of each post. The spikes should be placed about 3¾ feet to 4 feet above the ground, depending upon the height of the man who will do the drilling for the nozzles. Where pipe posts are used, the pipe can be held in place for drilling by wrapping a tight wire twice around the posts, then looping the wire around the nozzle pipe line so that the pipe will hang several inches below where it is attached to posts. The pipe is then fastened rigidly so that it can not turn while being drilled. A good way to do this is to replace the handle in the turning union with a 10 or 12 foot length of $\frac{3}{4}$-inch pipe, so that one end will rest on the ground, acting as a wrench holding the entire line. The nozzle holes are then spaced with a stick cut the proper length and marked with crayon. Three to four feet is the usual distance between the nozzles.

The nozzle holes must be in a straight line along the shell of the pipe. To accomplish this a special drilling machine is used. This machine hangs on the pipe and can be set in a perpendicular position by means of an attached level bubble. It is securely clamped for each drilling and the hole is made on the lower side of the pipe. The shank of the drill is a thread tap, so that the hole is threaded by running the drill into the pipe at the completion of the hole. Lard oil only should be used on the drill, as mineral oils cause the metals to heat and pinch the drill. A drop or two of oil placed on the upper side of the pipe will run to the lower side and be sufficient for each hole.

When the drilling of a line is complete the pipe is placed in its permanent supports and connected to the feed pipe. It always is desirable to run the water through the lines before screwing in the nozzles. This will wash out all the foreign materials in the pipe, and the nozzles can be put in at any time. When the water is first pumped through after the nozzles are in place, the end of the pipe should be left open for a time and each nozzle inspected. Scales or dirt in a nozzle can be dislodged by striking the opposite side of the pipe a sharp blow with a hammer while a finger is placed over the nozzle. A small wire thrust into the nozzle and quickly withdrawn also assists in removing obstructions.

COST DATA.

Cost data for material can be given only for general estimating purposes, as the markets fluctuate and the prices must vary also with the freight to different points.

Manufacturers have a standard list of prices on pipe and fittings from which discounts are given, according to the condition of the metal market, freight rates, and size of order. The standard lists are given in Table 7, with the probable range of discounts based on Pittsburgh, Pa.

TABLE 7.—*Standard list prices on wrought-iron and steel pipe, black and galvanized.*

Diameter in inches.	List price per foot.	Weight per foot, threads and couplings.	Threads per inch.	Diameter in inches.	List price per foot.	Weight per foot, threads and couplings.	Threads per inch.
¾	$0.11½	1.134	14	3½	$0.92	9.202	8
1	.17	1.684	11½	4	1.09	10.889	8
1¼	.23	2.281	11½	5	1.48	14.810	8
1½	.27½	2.731	11½	6	1.92	19.185	8
2	.37	3.678	11½	7	2.38	23.769	8
2½	.58½	5.819	8	8	2.50	25.000	8
3	.76½	7.616	8				

APPROXIMATE RANGE OF DISCOUNTS.

	Per cent off list.
Black wrought-iron pipe, random lengths	65 to 75
Galvanized wrought-iron pipe, random lengths	55 to 65
Black wrought-steel pipe, random lengths	70 to 80
Galvanized wrought-steel pipe, random lengths	65 to 75
Cast-iron and malleable fittings	65 to 75

TABLE 8.—*Standard list prices on black fittings for wrought iron and steel pipe.*

	Diameter of pipe (inches).													
	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6	7	8
Ells, R. H.	0.08	0.10½	0.16	0.20	0.28	0.50	0.75	1.05	1.20	1.75	2.00	2.75	4.70	6.75
Ells, reducing and R. & L.	.09	.12	.18	.23	.32	.60	.85	1.20	1.40	2.00	2.30	3.15	5.40	7.75
Ells, 45°	.10	.12	.19	.24	.34	.60	.90	1.25	1.45	2.20	2.50	3.45	5.90	8.50
Ells, side outlet	.24	.30	.48	.60	.84	1.50	2.2	3.15	3.60	5.25	6.00	8.25	.....	.....
Tees	.12	.15	.23	.29	.41	.73	1.15	1.50	1.75	2.55	3.00	4.00	6.80	9.75
Tees, reducing	.14	.17	.27	.33	.47	.83	1.25	1.75	2.00	2.95	3.50	4.60	7.80	11.25
Crosses	.22	.27	.42	.53	.75	1.30	2.00	2.70	3.15	4.60	5.50	7.25	12.25	17.50
Caps	.08	.11	.15	.22	.26	.40	.54	.75	.87	1.05	1.20	1.55	2.50	2.85
Sockets, reducing	.12	.18	.25	.36	.43	.60	.80	1.00	1.35	1.85	2.00	2.70	5.35	6.75
Bushings	.05	.06	.07	.09	.14	.21	.30	.40	.50	.75	.93	1.25	1.87	2.75
Plugs	.03	.04	.05	.07	.10	.18	.25	.38	.42	.65	.88	1.20	1.85	2.75

GALVANIZED FITTINGS FOR WROUGHT IRON AND STEEL PIPE.

Ells, R. H.	0.16	0.21	0.32	0.40	0.56	1.00	1.50	2.10	2.40	3.50	4.00	5.50	9.40	13.50
Ells, reducing	.18	.24	.36	.46	.641	.20	1.70	2.40	2.80	4.00	4.60	6.30	10.80	15.50
Ells, 45°	.20	.24	.38	.48	.68	1.20	1.80	2.50	2.90	4.40	5.00	6.90	11.80	17.00
Tees	.24	.30	.46	.58	.82	1.46	2.20	3.00	3.50	5.10	6.00	8.00	13.60	19.50
Tees, reducing	.28	.34	.54	.66	.94	1.66	2.50	3.50	4.00	5.90	7.00	9.20	15.60	22.50
Crosses	.44	.54	.84	1.06	1.50	2.60	4.00	5.40	6.30	9.20	11.00	14.50	24.50	35.00
Sockets, red	.16	.25	.35	.45	.86	1.20	1.60	2.00	2.70	3.70	4.00	5.40	10.70	13.50
Bushings	.10	.12	.14	.18	.28	.42	.60	.80	1.00	1.50	1.85	2.50	3.75	5.50
Plugs	.06	.08	.10	.14	.20	.36	.50	.76	.84	1.30	1.75	2.40	3.70	5.50

AVERAGE COST OF STANDARD BRASS SCREW GATE VALVES.

¾ inch	$0.60	1 inch	$0.85
1¼-inch	1.10	1½-inch	1.50
2-inch	2.25		

AVERAGE COST OF STANDARD IRON BODY SCREW GATE VALVES.

2½-inch	$2.85	5-inch	$7.00
3-inch	3.50	6-inch	8.00
3½-inch	4.25	7-inch	12.25
4-inch	5.25	8-inch	13.50

The smaller the pump the greater the cost per gallon capacity. Small displacement pumps of 10 to 50 gallons per minute capacity range in cost from $4 to $1 per gallon per minute capacity. Pumps having capacities of 50 to 100 gallons per minute range in cost from $3 to $1 per gallon per minute capacity. Larger pumps of the duplex and triplex types range as low as $1 per gallon per minute capacity. These cost figures are for surface displacement pumps and do not apply to deep-well equipment, which must vary according to local requirements.

The cost of centrifugal pumps is less than that of displacement pumps having the same capacity, but the same general rule holds that the smaller the pump the greater the cost per unit capacity. It seldom is feasible to use a centrifugal pump for spray irrigation where the requirement is less than 125 gallons per minute. The cost can be assumed to range from $1.25 per gallon per minute capacity for the small pumps to 10 cents per gallon per minute capacity for large pumps. The figures are for horizontal high-pressure centrifugal pumps for belt or direct drive and do not apply to vertical-shaft or deep-well turbine pumps, the cost of which varies according to local requirements.

Pumps are made in definite sizes, each size having an economic capacity. The irrigation system should be designed to fit some standard-sized pump, so far as possible, in order to make the most economical installation in first cost and in operation.

TABLE 9.—*Range in prices per horsepower for electric motors.*

Horsepower.	Alternating current.		Direct current.	
	High speed per horse-power.	Low speed per horse-power.	High speed per horse-power.	Low speed per horse-power.
1	$41	$81	$48	$54
5	14	35	23	26
10	14	27	20	23
30	12	20	15	16
25	11	20	13	16
35	9	18	....	....

The cost of gas and oil engines varies according to type, materials of construction, surface finish, ignition system, fuel equipment, etc. In the case of engines built for gas and the lighter oils, like gasoline, kerosene, etc., the four-cycle engines usually are much heavier than the two-cycle, and their cost ranges somewhat in proportion. Four-cycle engines of this type may be estimated at a cost of $25 to $40 per horsepower, while two-cycle engines range from $18 to $25 per horsepower. Heavy oil engines are built in greater weight, regardless of cycle, and their cost should be estimated from $40 to $50 per horsepower.

For estimating purposes electric motors may be divided into two general classes, those running on alternating current and those running on direct current. The chief factor affecting the price of a given motor is the speed for which it is built—the lower the speed the higher the price. Table 9 gives the range in price per horsepower for simple types of motors adaptable to ordinary pumping conditions. The prices do not include cast-iron sliding bases, pulleys, wiring, etc.

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