Selection and Design of—

Irrigation Systems

by Robert P. Beasley

Farmers can assure themselves of a feed supply and crop production during periods of rainfall deficiency by using irrigation. Before planning to irrigate, however, a farmer should investigate the quantity and quality of water available on his farm, and be sure that sufficient labor can be provided without interfering with other farm work. The amount of investment needed is another point to consider.

To insure maximum returns from irrigation, it is essential that the soil fertility be high, that adapted and suitable crop varieties be used, and that the best cultural practices be followed.

The ideal soil for irrigation has a deep, permeable, highly fertile topsoil, which absorbs water rapidly and has a large water-holding capacity. Such soils, however, are better able to withstand drought. Shallow, sandy soils have a low water holding capacity. They are usually low in fertility and are more subject to drought damage. Thus, sandy soils need to be irrigated more frequently and require more fertilizer. Heavy soils do not absorb water as readily as light-textured soils. It may be difficult to maintain their physical condition under continual irrigation. Establishing and maintaining high fertility and good tilth must be part of every successful irrigation program.

In humid regions there is always the possibility of rain occurring soon after irrigation, often in large amounts and high intensities. The effect of such additional moisture on crops, erosion, and leaching must not be overlooked.

These and other factors to be considered in the selection and design of an irrigation system are discussed in this bulletin.

WHEN TO IRRIGATE

Not all the moisture in a soil can be used by plants. That portion which can be used is known as "available soil moisture." When the soil moisture is reduced below this level, plants wilt and die. In general, irrigation for most field crops should begin when the amount of available soil moisture has dropped to approximately 50 percent. If this is done, the available soil moisture in the last of the area irrigated may be down to about 40 percent before additional water can be applied. It is considered good practice to design an irrigation system to supply the water needed above this 40 percent level. A large system that can cover the area faster will maintain more uniform moisture conditions.

Each irrigation, regardless of the amount of water applied, requires a certain minimum of labor. Every irrigation also results in loss of water by evaporation from the soil surface. For these reasons, water should not be applied more frequently than is necessary to keep crops growing at a satisfactory rate.

In arid regions where practically all water is applied by irrigation, the fields are irrigated in rotation, thus giving a definite interval between irrigations. In humid regions, rainfall may interrupt any schedule. As indicated, it is a good plan to start irrigation when the available soil moisture has been reduced to about the 50 percent level—unless there are definite indications of rain. It is a common mistake, however, for irrigators to delay irrigation too long in hopes of rain.

Testing Soil Moisture

Different methods may be used to determine the available soil moisture in the root zone. A sample of the soil may be taken and an actual determination made. This requires laboratory facilities and is seldom justified. Portable meters are available which determine the approximate soil moisture by measuring the electrical resistance of a block of porous material buried in the root zone. Ordinarily, a farmer with experience can estimate the soil moisture to a fair degree of accuracy by the feel of the soil. A soil auger, sampling tube, or spade can be used to take a sample of soil midway in the root zone. The sample is squeezed in the hand and the moisture content estimated. Table 1 will serve as a guide when using the feel method of estimating the need for irrigation.
### TABLE 1 -- ESTIMATING MOISTURE CONTENT BY THE FEEL OF THE SOIL

<table>
<thead>
<tr>
<th>Moisture Content</th>
<th>Soil Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse</td>
</tr>
<tr>
<td>Low. Irrigation Needed</td>
<td>Appears dry, will not form a ball under pressure.</td>
</tr>
<tr>
<td>Good. Irrigation Not Necessary</td>
<td>Forms a ball under pressure but breaks easily.</td>
</tr>
</tbody>
</table>

### TABLE 2 -- AMOUNT OF SOIL MOISTURE NEEDED AND FREQUENCY OF APPLICATION DURING THE PERIOD OF PEAK USE BY THE PLANTS*

<table>
<thead>
<tr>
<th>Soil Class</th>
<th>Depth of Crop Roots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shallow-(1 1/2 ft.)</td>
</tr>
<tr>
<td></td>
<td>Needed inches</td>
</tr>
<tr>
<td>Low Water Holding Capacity</td>
<td>0.9</td>
</tr>
<tr>
<td>Medium Water Holding Capacity</td>
<td>1.3</td>
</tr>
<tr>
<td>High Water Holding Capacity</td>
<td>1.8</td>
</tr>
</tbody>
</table>

*Assuming that 40 percent of available moisture remains in the soil root zone at the beginning of irrigation and an irrigation efficiency of 75 percent.

### TABLE 3 -- SUGGESTED MAXIMUM APPLICATION RATES, INCHES PER HOUR.

<table>
<thead>
<tr>
<th>Soil Class</th>
<th>Land Slopes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-5 percent</td>
</tr>
<tr>
<td></td>
<td>Bare</td>
</tr>
<tr>
<td>Sandy</td>
<td>1.0</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>0.6</td>
</tr>
<tr>
<td>Silt Loam</td>
<td>0.4</td>
</tr>
<tr>
<td>Heavy Silt Loam and Clay</td>
<td>0.3</td>
</tr>
</tbody>
</table>
The appearance of the crops also may indicate the need for irrigation. With most crops, the leaves turn a darker bluish-green when they begin to suffer from lack of water. If irrigation is not started before this stage, however, serious damage may result before an entire field can be irrigated.

**Amount of Water to Apply**

The amount of water to apply depends upon two things—

1. the depth of the root system of the crop
2. the water-holding capacity of the soil.

Sufficient water should be applied to penetrate to a depth that will include a majority of the feeder roots of the plants. If more is applied, the expense will be greater and there may be some leaching of plant food from the root zone by deep percolation. Smaller applications at more frequent intervals may result in a shallow-rooted crop and reduced yields.

Table 1 may be used as a guide to determine the amount of water to apply to different soils and crops. Vegetables are considered shallow-rooted, pastures medium-rooted, and grain, cotton and alfalfa as deep-rooted plants. The sandy and gravelly soils of the Ozark uplands, the creek and river bottoms, and the southeast Missouri lowlands would be considered low in water-holding capacity. Sandy loam soils are considered medium, and the silt and clay loam soils high in water-holding capacity.

It is advisable to determine the depth that water penetrates into a soil following irrigation. It may be found that the soil has an exceptionally high or low water-holding capacity, and that amounts of moisture indicated in Table 1 need to be adjusted. The depth of penetration should be checked approximately two days following an irrigation. A soil auger, sampling tube, or spade can be used to determine this depth.

**Frequency of Irrigation**

The interval between irrigations depends on the moisture-holding capacity of the soil, on the crop, on the stage of growth, and on the weather. Table 2 suggests average intervals desirable between irrigations when crops are using moisture at peak rates and when there is no rainfall.

**Rates of Application**

The rate that irrigation water can be applied is determined by the infiltration rate of the soil. Infiltration rates are usually slower on steep slopes. Heavy crop covers increase the infiltration rate. Suggested maximum rates of water application are given in Table 3. Higher rates than these may result in waste of water and soil erosion. The application rate usually should not be less than 0.15 inch per hour, to avoid excessive evaporation losses and labor requirements.

**Irrigation of Different Crops**

Pasture and forage crops require relatively large amounts of water for maximum yields because of their long growing season. These crops, due to their ability to use larger amounts of water, will respond more favorably to irrigation than some other field crops. Pasture crops with roots of medium depth require lighter and more frequent irrigations than deeper rooted crops like alfalfa. Alfalfa should not be irrigated immediately after cutting. The growth of undesirable grasses may be stimulated, causing them to compete with the alfalfa which is in a dormant state for several days following cutting.

Corn requires relatively small amounts of water during the early stages of growth. It requires the greatest amount of moisture from the time it tassels until the ears are in the early milk stage. Light, frequent irrigations in the early stages may result in a shallow root system and may reduce yields.

Soybeans have not responded as well to irrigation as corn. They are apparently more drought resistant than corn. One handicap, at present, is that less information is available as to the stages of soybean growth during which shortages of moisture are most critical.

Cotton has a relatively low water requirement during the early stages of growth. The demand for water becomes heavy when the first bloom appears and continues until the peak of the fruiting season.

Small grains grow during the time of year when moisture shortages are not usually critical. The irrigation of these crops for grain production probably will not be profitable. It may be of value for germination or if the small grain is to be used for pasture.

The greatest returns from irrigation probably will be from the irrigation of fruits and vegetables because of the high value per acre.

The material presented in the preceding sections should be considered as a guide. Changes may be necessary as more knowledge is obtained.
WATER REQUIREMENTS

The first consideration should be given to the availability of a water supply of suitable quality and adequate quantity at reasonable cost.

Quantity.

The supply of water must be sufficient to furnish the quantity of water needed at sufficient rate to irrigate an area in the time allotted. The following units of measurement may be useful:

An acre-foot is the amount of water necessary to cover an acre with a layer of water 1 foot deep. This is equal to 326,000 gallons.

An acre-inch is the amount of water necessary to cover an acre with a layer of water one inch deep. This is equal to 27,154 gallons. For example, a 2¾-inch irrigation on a 20-acre field will require approximately 1½ million gallons of water.

One cubic foot per second, or 450 gallons per minute, will supply one acre-inch per hour. A cubic foot per second is the rate of application required to cover an acre with 1 inch of water in one hour, if there are no irrigation losses. With a flow of 4½ gallons per minute, which is the capacity of many deep wells used for household purposes, it would take 100 hours to apply one inch of water on one acre.

The quantity of water needed for irrigation during a growing season will depend upon the rainfall and other climatic factors, the moisture holding capacity of the soil and the crop grown. The depth of the soil profile influences the moisture holding capacity of a soil. Soils are considered shallow when their profile is such that the depth of rooting is less than 2 feet, medium when the depth of rooting is more

<table>
<thead>
<tr>
<th>Soil Type and Location</th>
<th>Additional Soil Moisture Needed, Inches</th>
<th>Quantity Irrigation Water Required, Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow soils of low water holding capacity in South Missouri</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Shallow soils of medium water holding capacity in South Missouri</td>
<td>10</td>
<td>13½</td>
</tr>
<tr>
<td>Deep soils of medium water holding capacity in South Missouri and Medium depth soils of medium water holding capacity in North Missouri</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Medium depth soils of high water holding capacity and Deep soils of medium water holding capacity in North Missouri</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Deep permeable soils of high water holding capacity in North Missouri</td>
<td>7</td>
<td>9½</td>
</tr>
</tbody>
</table>
than 2 feet but less than 3 feet, and deep when the rooting is more than 3 feet. The amount of water that should be added to the crop root zone to supply moisture for field crops during a drought year of the severity that may be expected once in 25 years is given in Table 4.

In years of less severe drought smaller quantities of water may be quite valuable. The application of a single irrigation to a crop during its critical-need period will usually result in an increased yield. Because of losses through evaporation, seepage and run-off, more water will be needed for irrigation than that actually used by the plants. Under good irrigation practice in Missouri, only about 75 percent of the water supplied is used by the plants. The number of inches of irrigation water necessary to supply the crops, assuming a 75 percent irrigation efficiency, is given in Table 4.

Quality.

Water contains varying quantities of dissolved salts. Some of these salts, such as calcium and magnesium, if their concentration is not too great, may improve the soil and the growth of plants. Others, such as sodium, may be detrimental.

The streams of Missouri, in general, do not contain salts in sufficient quantity to be harmful and, therefore, are of excellent quality for irrigation.

Deep wells in water provinces 3 and 4, Figure 1, may produce “mineralized water” in which the salt concentration is high enough to be harmful to the soil and plants. Water from deep wells in these areas should be tested to determine its suitability before it is used for irrigation. Information on collecting samp-
les, testing, and interpreting results may be obtained from the University of Missouri College of Agriculture.

Some of the streams in the state may be contaminated by acids and industrial wastes. Such water should be tested also before it is used for irrigation.

Too much silt in irrigation water might cause undue wear in pumps and sprinklers. At the time crops are irrigated the silt carried in most streams in the state will cause little trouble. Water containing appreciable silt should not be used, however, in water-lubricated pump bearings.

**Water Rights**

The only law in effect in Missouri at this time (1954) is the Law of Riparian Rights, which says that each land owner along a stream has an equal right to a reasonable use of its waters for domestic, agricultural, and manufacturing purposes so long as he does not interfere unreasonably with equal rights of other downstream land owners to the use of the stream flow.

Several land owners using water from a stream of insufficient flow could lead to injunctions and lawsuits. The question of how much water any individual can use, the courts have said, is a question of fact to be determined by the circumstances of the individual cases.

There is no law covering the use of water from wells or private lakes.

**Sources of Water***

**Streams**

For irrigating purposes, streams and rivers can be classified as permanent or ever-flowing, and as intermittent or seasonally dry. Streams that flow the year around have a source of water that comes from permanent ice or snow fields or underground seepage and springs. Intermittent streams depend on surface runoff and may dry up between rains.

In Missouri, the character of the stream flow is of importance to irrigation. For example, the supply of water available for irrigation is much less in the southward flowing streams of north Missouri than in the spring fed streams of the Ozarks where the water comes from springs and seepage.

The major rivers of Missouri have sufficient flow to be used for irrigation. Flow records of these major streams are available from 1921 to the present. These records are available from the State Geologist, Rolla, Mo., and he should be consulted before large-scale water use is undertaken.

Many of the smaller streams are capable of meeting the needs for irrigation of a limited acreage. In some instances a reservoir may be used in conjunction with a small stream to store water during periods of high runoff for use during periods of low flow. The gravel deposits in a small stream bed may contain large quantities of water after the stream quits flowing. This water can be obtained by digging sump pits at the lower end of the gravel beds. It may be advisable to have sumps at the ends of several gravel beds, rather than attempt to pump all the water from a single sump. Such a system will provide more water and extend the time during which it is available.

**Ground Water**

The ground water within the earth has accumulated over a long period of time. Since this ground water is not free to flow like rivers, the rate of movement is slow and it takes considerable time to replace it when it is depleted. Any irrigation project using ground water should take this into consideration in determining the pumping rate.

Persons contemplating the development of an irrigation system using ground water should consult the office of the State Geologist in Rolla for information on ground water in the vicinity of their proposed installations.

The State Geologist has records from more than 18,000 wells and prospect holes. From these records he will, in most cases, be able to give an opinion on whether enough water is available and the depth at which a given quantity can be obtained. Of equal importance is the information he can give concerning the quality of such waters.

It is difficult to make specific statements as to ground water conditions in the state, particularly in areas where the water must come from wells in bed rock. Because a rock stratum is a large producer at one location, does not mean that it will be an equally large producer in other areas. Consequently, the yields to be expected in different areas cannot be predicted accurately. In general, however, the state may be divided into four ground water provinces (See Figure 1).

Province 1 includes the alluvial lowlands of southeastern Missouri and the alluvial plains of the Missouri, Mississippi, Grand, Chariton and other

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*Acknowledgement is due Dr. E. L. Clark, State Geologist, Rolla, Missouri for much of the information on streams and wells given in this section.
large rivers of the state. Wells in these areas generally should be expected to yield large quantities of water at relatively shallow depths. For example, a well near Wardell in Pemiscot County has a capacity of 4,700 gallons per minute at a depth of less than 100 feet.

Ground water in the rest of the state must come from bed rock. The depth of the well and the expected yield cannot be predicted with any degree of certainty. The following general statements may be made.

In Province 2 there are possibilities of deep well supplies adequate for irrigation but at greater expense. Such wells will have to be deep and penetrate several water bearing strata to obtain supplies in excess of 100 gallons per minute.

In Province 3, mineralized water unsuitable for irrigation is usually encountered in the deeper wells. Shallower wells may provide water of suitable quality but they usually do not yield sufficient quantity for irrigation.

In Province 4, wells in bed rock at depths greater than 350 to 400 feet usually produce water too mineralized for irrigation. Wells of shallower depths, while producing water of satisfactory quality, may not yield more than 25 gallons per minute, which is insufficient for irrigation. Larger quantities are available from the preglacial valleys which have been filled with an alluvial deposit of silt, sand and gravel but the supplies are still too limited for irrigation of field crops in most cases.

A properly constructed well is important if maximum use is to be made of the ground water supplies. The diameter of a well is not as important in obtaining large yields as depth. A 12-inch rock well will yield only 11 percent more water than a 6-inch well at the same location with the same drawdown of the water level. An alluvial well, 4 inches in diameter, would have to be enlarged to more than 80 inches to double the yield, other factors remaining the same.

There are some advantages of large diameters. In alluvial wells, a larger diameter will reduce the velocity of the flow of water into the hole and thereby reduce sand pumping and sand and silt sealing. In rock drilled wells, the diameter will be determined largely by the method of casing and the size and type of pump to be installed. A large diameter will facilitate deeper drilling to another water bearing zone in the event a larger yield is required at a later date.

An alluvial well should penetrate the entire alluvium to bed rock to obtain the maximum yield, unless a major zone of production is encountered at a shallower depth. Penetration of the entire thickness of the water-bearing strata is important in the rock well, too. Too frequently, wells are stopped just short of a depth which would give maximum flow. A geological log of the well during drilling and a knowledge of the water-bearing capacity of the various rock strata will be of help. The drilling can be continued to too great a depth. It is not economical to drill below a water producing zone that will supply water sufficient for all needs. A prospect or test hole is often put down prior to drilling an alluvial well to determine the most desirable location and depth.

Most wells in bed rock are drilled with a churn or percussion drill. Alluvial wells may be drilled with the rotary type drill or by a specially constructed bailer. The hole usually is drilled larger than the well casing and a layer of gravel is placed around the well casing and screen. Alluvial wells also may be dug by hand, by clam shell excavator or they may be driven. The driven well consists of a pipe and a sand point which is driven into the water-bearing material. The sand point is a pointed perforated pipe wrapped with a fine mesh wire screen and covered with a perforated jacket to protect the screen during driving. The points vary from 1 1/4 to 6 inches in diameter and up to 10 feet in length. The larger sizes generally are used for irrigation. It may be necessary to drive several points in the immediate vicinity and pipe them to a single pump to obtain the desired capacity. Sand point wells are best suited to areas with a shallow water table in which the maximum suction lift, including drawdown, does not exceed 15 feet. These wells are pumped from the surface with a centrifugal pump.

The services of a well driller are required in the construction of most wells. It might be possible for an individual to construct one of the small capacity, alluvial wells but it would be advisable for him to obtain information from a competent and experienced person on the most desirable type of well to install.

Lakes and Ponds.

The amount of water required for irrigation in a drought year of the severity that can be expected once in 25 years is given in Table 4. In a well-constructed pond or lake these amounts should be increased by one-third to allow for seepage and evaporation losses. Losses will exceed this amount if the pond is not constructed in such a way that seepage losses are practically negligible. Evaporation losses from the surface in a dry year will amount to about 4 1/2 feet. The percent of water lost by evaporation is reduced appreciably by having a small surface area and greater depth of water.

Table 5 gives the amount of storage required per
acre irrigated, and the size of drainage area needed to supply it, in all except the most severe drought years. In years of normal rainfall there will be an appreciable runoff from these large drainage areas which creates problems in spillway design.

Lakes or reservoirs may be used in conjunction with a small stream to store water in the spring for irrigation later when the stream flow is at a minimum.

### TABLE 5 -- RESERVOIR CAPACITY AND SIZE OF DRAINAGE AREA NEEDED FOR EACH ACRE TO BE IRRIGATED.

<table>
<thead>
<tr>
<th>Soil Type and Location</th>
<th>Reservoir Capacity, Acre Feet</th>
<th>Size of Drainage Area, Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow soils of low water holding capacity in South Missouri</td>
<td>1 1/2</td>
<td>12</td>
</tr>
<tr>
<td>Shallow soils of medium water holding capacity in South Missouri</td>
<td>1 1/2</td>
<td>10</td>
</tr>
<tr>
<td>Medium depth soils of high water holding capacity underlain by heavy subsoil in Central Missouri</td>
<td>1 1/2</td>
<td>8</td>
</tr>
<tr>
<td>Medium depth soils of high water holding capacity in North Missouri</td>
<td>1 1/2</td>
<td>12</td>
</tr>
<tr>
<td>Deep permeable Soils</td>
<td>A reservoir probably is not a practical source of water supply for these soils because of the large drainage areas required to supply the water.</td>
<td></td>
</tr>
</tbody>
</table>

### CHOOSING METHODS OF IRRIGATION

Supplemental water may be applied to crops by surface irrigation or by sprinkling. Most of the irrigation in Missouri has been by the sprinkling method. As the use of irrigation expands there may be areas in the state where the use of surface irrigation will be increased. The following factors should be considered in selecting the type of irrigation system.

**Topography Considerations**

Land should be smooth for surface irrigation so that no areas will be exposed or excessively covered when water is applied. Surface irrigation is best adapted to uniformly sloping land with slopes ranging from 0.2 to 3 percent. On steeper or more irregular slopes it becomes more difficult to distribute the water evenly and soil losses through erosion may be excessive. Sprinkler irrigation is better for land with variations in topography.

**Soil Type Factors**

Surface irrigation of the more open soils usually results in excessive losses of water through deep percolation. Soils of medium or heavier texture are better suited to surface irrigation, although there may be some losses through deep percolation and runoff. Practically any soil can be irrigated by a properly designed sprinkler system with little or no loss through deep percolation or runoff. With either type of system it will be more difficult to maintain a good physical condition on the heavier soils.

**Water Requirement**

Seepage losses through distribution ditches, deep percolation losses, and surface runoff in surface irrigation result in greater water requirements for surface irrigation than for sprinkler irrigation. This excess
water may result in excessive soil erosion, leaching of plant foods, and drainage problems.

**Preparation of the Land**

If slopes are not uniform and free of irregularities, land leveling will be necessary for an efficient job of surface irrigation. On thin soils these leveling operations require the removal of a large percentage of the top soil from some areas, resulting in variations in soil fertility. Ditches for delivering water take up space and hinder farming operations. Leveling operations and ditching are expensive and must be done prior to the time of seeding. Land leveling is not required for sprinkler irrigation. In both methods of irrigation some land smoothing prior to the seeding of the crop may be advisable. This land smoothing can be done with floats or land planes pulled with a farm tractor.

In some areas where there is little natural slope to the land and drainage is a problem, the land preparation can be done in such a manner that sufficient slope will be provided for surface irrigation and drainage will be improved. This is accomplished by a modification of the "bedding" system in which the field is graded into a series of ridges which slope uniformly to shallow drainage channels midway between them. The irrigation water is run down the top of the ridges in a ditch or pipe from which it is distributed to land on each side of the slope.

**Initial Cost**

The initial cost of a sprinkler system depends on the acreage irrigated and the availability of water (see Table 10). Land preparation costs for surface irrigation vary widely, depending on the amount of leveling and ditching required. On land that requires a medium amount of leveling, these costs may range from $25 to $50 per acre.

**Power Requirements**

A sprinkler system requires water under pressure. Usually, this pressure must be produced by pumping, which increases the expense. In surface irrigation, it is necessary only to deliver the water to a point from which it can be distributed.

**Labor Requirements**

The extra labor required for irrigation will vary with the design of the system and the crop irrigated. It may range from one-half to three man hours an acre per irrigation. The labor required is about the same for both methods of irrigation. However, more experience is required for surface irrigation.

Pastures and other short, close growing crops are easier to irrigate with a sprinkler system than are the tall growing row crops. They provide a solid footing even when wet; the growth is not tall enough to interfere with moving the pipe; and long risers are not required.

Labor requirements for surface irrigation can be reduced by a thorough job of land leveling and for sprinkler irrigation by mechanical move systems that are now available.

**Wind**

Winds affect the distribution of water by a sprinkler system and increase the evaporation.

**Crop Yields**

There is no evidence to indicate that either method is more desirable than the other in increasing production.

**Soil Erosion**

The effect of the additional water on crop damage, soil erosion, and leaching must be considered with either type of system. The ditches and dikes necessary for distribution of water in surface irrigation on sloping land, may overtop during heavy rains and cause excessive erosion.

**DESIGN OF IRRIGATION SYSTEMS**

The proper design of an irrigation system requires a knowledge of surveying, hydraulics, soils management, crop management, and irrigation principles and practices. It is the purpose of this bulletin to give basic information upon which irrigation systems may be designed. Good designs for particular farms can be developed only after a thorough study of each case.
TABLE 6 -- RATE OF FLOW NECESSARY TO STORE ONE ACRE INCH OF WATER IN THE SOIL*

GALLONS PER MINUTE

<table>
<thead>
<tr>
<th>Days to Irrigate the Area</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>16</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>15.0</td>
<td>12.0</td>
<td>10.0</td>
<td>7.5</td>
<td>6.0</td>
</tr>
<tr>
<td>10</td>
<td>7.6</td>
<td>6.0</td>
<td>5.0</td>
<td>3.8</td>
<td>3.0</td>
</tr>
<tr>
<td>15</td>
<td>5.0</td>
<td>4.0</td>
<td>3.3</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>20</td>
<td>3.8</td>
<td>3.0</td>
<td>2.5</td>
<td>1.9</td>
<td>1.5</td>
</tr>
</tbody>
</table>

* Based on an irrigation efficiency of 75 percent.

A given period of time can be determined by the formula $Q = \frac{453 Ad}{FH}$ in which $Q$ is the discharge in gallons per minute, $A$ is the number of acres to be irrigated, $d$ is the depth of irrigation in inches, $F$ is the number of days allowed to irrigate the area and $H$ is the hours of irrigation per day. Because of losses through evaporation, seepage, and runoff, the amount of water supplied must be greater than the amount actually needed by the crop. Under good irrigation practice in Missouri about 75 percent of the water supplied can be made available for plant use. Table 6 gives the number of gallons per minute that must be supplied to store 1 inch of water on one acre. For example, assume that 20 acres of alfalfa on a soil of medium water holding capacity is to be irrigated. This crop will require 3.6 inches of water each 12 days during its peak use period (see Table 2). If 1 inch of water were to be applied by irrigating 16 hours per day for 12 days, the rate of supply would be 3.3 gallons per minute (see Table 6). To apply 3.6 inches on one acre would require 3.3 times 3.6 or 11.9 gallons per minute. To irrigate the 20 acres, 11.9 times 20 or 238 gallons per minute will be required.

The farm operations schedule for planting, cultivating, and harvesting, as well as labor requirement for routine farm operation, must be considered when planning the irrigation system so that the irrigation can be accomplished with as little interference with other farming operations as possible.

A large system will irrigate a given area faster and with less labor than a smaller, less expensive system. The size of system to use often is influenced by the money and labor available.
SURFACE IRRIGATION

If irrigation is to be accomplished by flooding methods, it may be desirable to prepare a map of the area, showing contour lines at a 1-foot vertical interval, soil type, and soil profile. This map can be used to determine the layout of ditches and dikes, as well as the amount of land leveling that will be required to insure uniform distribution of water.

Furrow Irrigation.

Corn and other crops planted in rows form furrows through which the irrigation water is run. Supply ditches, or field laterals, are located along the upper border of the field and at intervals down the slope to give the desired length of furrow. It is important to accurately regulate the flow to each furrow. A secondary ditch, called a regulation bay, that can be used to accomplish this is illustrated in Figure 2. Siphon tubes may be used to distribute water from the supply ditch to the furrows, in which case the regulation bay is not needed. A canvas or plastic dam is used to raise the water level in the field lateral (see Figure 3). If water is piped from the source of supply, gated pipe or plastic hose may be used to regulate the flow to the furrows (see Figure 4).

The length of furrow that can be used is determined by the soil, the slope of the field, and the size of the stream that enters the furrow. Long furrows on a porous soil result in excessive deep percolation and wasting of water at the upper end of the furrow. The length of furrow can be determined best by a trial irrigation, during which the depth of penetration along the furrow can be checked.

Suggested lengths of furrow to use for a trial irrigation on different soil types and on slopes of less than 2 percent are given in Table 7.

The size of stream to use in each furrow will vary, depending on the soil and on the slope in the furrow. At the start of the irrigation, the largest stream possible without causing erosion in the furrow should be used so that water will reach the lower end of the furrow before excessive deep percolation occurs at the upper end. After the water reaches the lower end of the furrow, the flow should be reduced until just a trickle reaches the lower end. The flow should be continued until the desired degree of penetration is obtained. A suggested rate of flow for each furrow at the start of an irrigation is given in Table 7. A trial irrigation will indicate whether soil washing occurs and if adjustment of flow is necessary.

Irrigation furrows that run directly down the slope are not recommended on land steeper than 2 percent because of the severe erosion which may result from a heavy rain following irrigation. On land steeper than 2 percent that is planted to row crops, terraces may be needed to control erosion. Terraces can be

Figure 3—Distribution of water to furrow by use of siphon tubes. A canvas or plastic dam is used to raise the water level in the ditch higher than the surrounding ground. (U. S. Bureau of Reclamation photo).
Figure 4—Distribution of water to furrows by gated pipe. (W. R. Ames Company photo).

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Sandy Loam</th>
<th>Medium Silt Loam</th>
<th>Heavy Silt or Clay Loam</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>450</td>
<td>25</td>
<td>900</td>
</tr>
<tr>
<td>0.5</td>
<td>400</td>
<td>15</td>
<td>800</td>
</tr>
<tr>
<td>1.0</td>
<td>350</td>
<td>8</td>
<td>700</td>
</tr>
<tr>
<td>1.5</td>
<td>300</td>
<td>6</td>
<td>600</td>
</tr>
<tr>
<td>2.0</td>
<td>250</td>
<td>4</td>
<td>500</td>
</tr>
</tbody>
</table>

TABLE 8 -- SUGGESTED LENGTH AND WIDTH OF STRIPS AND RATE OF FLOW FOR BORDER IRRIGATION

<table>
<thead>
<tr>
<th>Soil</th>
<th>Length of Strip, Feet</th>
<th>Maximum Width of Strips, Ft.</th>
<th>Gallons per Minute per 10 ft. of width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Sandy Loam</td>
<td>300</td>
<td>30</td>
<td>300</td>
</tr>
<tr>
<td>Medium Silt Loam</td>
<td>600</td>
<td>40</td>
<td>250</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>800</td>
<td>50</td>
<td>200</td>
</tr>
</tbody>
</table>
used to assist in the distribution of irrigation water. Careful planning of irrigation supply channels and grades in crop rows must be made prior to planting, if this type of irrigation (called contour furrow irrigation) is to be successful. Accurate control of the flow to each furrow is necessary, because a break-over in one furrow would cause lower furrows to break over and result in severe erosion.

Border Flooding

The border method of irrigation is adapted to watering close-growing crops on slopes not exceeding 3 percent. Small ridges, or border dikes are run directly down the slope and the strips of land in between are leveled transversely so that the water will be distributed uniformly over the strip. Water is distributed to these borders by supply ditches, spaced as needed, depending on the length of the strip (see Figure 5). Suggested lengths and widths of strips and amounts of water to apply on different soils are given in Table 8.

Flooding from Contour Ditches

This method is adapted to the irrigation of close growing crops and to land that is relatively smooth so that little leveling is required to spread the water uniformly over the area. The supply ditches are built across the slope at a grade usually not exceeding 0.2 percent. The water is diverted from this ditch at intervals into a small furrow which is located exactly on the contour. The furrow slice is thrown uphill. Water overflows this furrow and spreads evenly over the area to be irrigated. See Figure 6. The supply ditches are spaced from 50 to 200 feet apart, depending on the soil, slope, and uniformity of the topography.

Basin or Contour Check

In this method of irrigation, water is applied to level or approximately level plots that are made into basins or checks by surrounding them with ridges of earth. The basins are flooded quickly with the quantity of water needed by the crop and penetration of water is obtained. This method works well on very tight soils with a low infiltration rate. It may also be used on sandy soils if excess deep percolation occurs with the other methods. It is the accepted method of irrigating rice and also may have limited application in the irrigation of other close growing crops.
SPRINKLER IRRIGATION

The three most common types of sprinkler irrigation systems are the stationary overhead, the perforated pipe, and the rotary sprinkler systems.

Stationary Overhead Sprinkler System

This system, often referred to as the Skinner system, is used extensively for irrigating vegetable, truck and nursery crops. Lines of pipe with brass nozzles inserted every 2 to 4 feet are placed 2 to 7 feet high and spaced up to 50 feet apart. These systems are usually stationary; hence, the initial cost per acre is relatively high, limiting their use to the high value crops.

Perforated Pipe Sprinkler System

This system consists of lightweight tubing equipped with quick couplers or of plastic hose with holes at various angles to distribute the water over a strip to each side. (See Figure 7). The use of this system is limited primarily to crops that are low enough that they do not obstruct the spray. They also are suitable for orchards. The pipe or hose is left in one position until the required amount of water is applied and then moved. The application rate may be too high for soils of medium or heavy texture.

Rotary Sprinkler System

This is the system most widely used in Missouri for the irrigation of field crops. (See Figure 8). There are many different types and sizes of sprinkler heads designed for specific purposes, such as under-tree sprinklers and part-circle sprinklers, in addition to the standard full-circle sprinklers commonly used in the irrigation of field crops. The capacities of these sprinklers range from 2 to more than 600 gallons per minute.

Water is usually distributed to the sprinklers by lightweight tubing equipped with quick acting couplers. Many companies manufacture sprinkler irrigation equipment. Various types of tubing, couplers, valves, and fittings are available. The method of coupling tubes or pipes together is the main difference among various makes. In some installations, the main line is left in one location and constructed of heavier, more durable material. In others, it may be underground.

Figures 9, 10 and 11 illustrate three of the many possible layouts of rotary sprinkler systems for rectangular shaped fields. System layouts for irregular areas usually require more planning.

There is a wide variation in types and sizes of sprinklers, in distance of lateral moves, and in sizes of pipes that may be used in any layout. A well designed system is one that will deliver the required amount of water at a rate that the soil can absorb, and one that will distribute it evenly at a minimum cost. The total cost of irrigation will be determined by the initial cost of the system and by its cost of operation. A system which uses a minimum amount of pipe, undersized pipe, or an inefficient pump may be low in first...
Figure 10—This system may be operated with either one or two laterals. If two laterals are used they can both be operated at the same time or one operated and the other moved to the next set. The valve-tees will enable the flow to each lateral to be adjusted to give the desired pressure. The flow to one lateral may be shut off completely and the lateral moved while the other continues operating. If valve-tees are not used the pump is shut down each time a lateral is moved.

Figure 11—This system requires a mainline one-half the length of the area to be irrigated, and a double valve to regulate the flow to each lateral. As lateral A is moved closer to the pump this will release mainline which can be used to move lateral B in the direction indicated. Both laterals may be operated at the same time or one operated while the other is moved to a new setting.

<table>
<thead>
<tr>
<th>Sprinkler Spacing, Feet</th>
<th>Discharge from Each Sprinkler - Gallons per Minute</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td>20 x 40</td>
<td>.48</td>
</tr>
<tr>
<td>30 x 30</td>
<td>.43</td>
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<tr>
<td>30 x 60</td>
<td>.21</td>
</tr>
<tr>
<td>40 x 40</td>
<td>.24</td>
</tr>
<tr>
<td>40 x 60</td>
<td>.16</td>
</tr>
<tr>
<td>60 x 60</td>
<td>.16</td>
</tr>
<tr>
<td>60 x 80</td>
<td>.16</td>
</tr>
</tbody>
</table>

*Rate for spacings other than those given may be determined by the formula –

Rate of Application = \( \frac{96 \times \text{gallons per min. per sprinkler}}{\text{Spacing of sprinkler on lateral, feet} \times \text{spacing of laterals, feet}} \)

Table 9). Rates of application should not be greater than those given in Table 3 nor less than 0.15 inches per hour.

Uniformity of Application

The uniformity of application is influenced by the capacity of the sprinklers, the pressure at the sprinklers, and the spacing of the sprinklers.
Variation in pressure at the sprinklers should be kept to a minimum. This reduces variation in the sprinkler discharge and assures a reasonably uniform distribution of water over the area irrigated. A satisfactory distribution will be obtained if the pressure variation along the lateral is limited to 20 percent of the highest pressure. Pressure differences in a lateral line are caused by friction in the pipe and by variations in elevation along the line. Friction losses may be reduced by using a larger pipe. Pressure losses due to changes in elevation may be minimized by designing the system so that the laterals may be laid across or down the slope.

Sprinklers are designed to operate within certain pressure ranges. If operated at higher or lower pressures the application of water will not be as uniform. At low pressure, the water droplets will be larger, possibly resulting in excessive puddling of the soil. High pressures increase pumping costs and give a fine spray which is more subject to wind drift and loss through evaporation. Suitable operating pressures for various sprinklers are supplied by the manufacturers.

The spacing of the sprinklers affects the uniformity of application. Manufacturers give spacing recommendations. The following spacings may be considered as a general recommendation. Where wind velocities do not exceed 5 miles per hour, the sprinklers on the laterals may be spaced up to 45 percent of the diameter of their coverage, and the lateral moves up to 65 percent of this diameter. Where wind velocities exceed 5 miles per hour, the spacing of sprinklers along the lateral should be reduced to 35 percent and the lateral moves to 50 percent of the diameter of coverage. These figures are based on a rectangular spacing of the sprinklers. If the triangular or staggered spacing is used, these spacings can be increased 10 percent. The effect of wind on uniformity of distribution can be reduced by laying the laterals at right angles to the wind direction.

Size of Main

The diameter of the main line should be such that the desired quantity of water can be supplied to all laterals without excessive loss of pressure. The initial cost of the pipe and the cost of power to overcome the friction in the pipe must be considered in selecting the size of pipe. For example, a smaller diameter pipe is lower in first cost, but in a few years the additional cost of power to overcome the greater friction may be more than enough to offset the saving in first cost. The maximum main line friction losses permissible depend largely upon the cost of power for pumping and the number of hours of operation per year. If the number of hours of operation per year is small and the cost of power is low, a smaller main is permissible.

It is evident that many technical design factors affect the cost and operation of a sprinkler irrigation system. For this reason, such systems should be designed by persons competent in this work.

It is good business to compare costs of different systems but not to base final selection on cost alone.

Types of Pumps

Horizontal Centrifugal Pumps are best suited to pumping from surface water supplies such as ponds and rivers. This type of pump usually is not recommended for suction lifts greater than 15 feet. The shorter the suction lift the higher its efficiency and capacity. For this reason, the pump should be located as close to the water supply as possible. This type pump can be used on wells where the depth from the pump to the water, while pumping, will not exceed 15 feet.

Centrifugal pumps are available which operate against pressure heads up to 500 pounds per square inch, and at capacities varying from a few gallons to as much as 720,000 gallons per minute, depending upon the size of the pump and the design of the impeller. Any particular pump, however, will have a narrow range of capacity and head within which it will operate at highest efficiency.

Centrifugal pumps usually must be primed before they will operate. This is commonly done with an
engine exhaust primer or with an auxiliary hand pump. A foot valve on the suction pipe is often used to prevent the pump from loosing prime when not running.

Because of its relative low cost, long life, ease of repair and its ability to deliver a steady flow, the centrifugal pump is well adapted for irrigation where the suction lift does not exceed 15 feet.

Turbine Pumps normally are used for pumping from deep wells. The bowls are submerged and the pump does not require priming. The pump may be driven by a vertical shaft connected to a motor on the surface, or it may be connected directly to an electric motor submerged with the pump.

A turbine pump usually is more expensive than a centrifugal pump of equal capacity.

Propeller Type pumps are used commonly where large quantities of water are to be pumped against heads not exceeding 30 feet.

Selection of Pumps

A pump may be expected to operate efficiently only within a narrow range of discharge rates and pressures. For this reason, it is desirable to select a pump that is designed to operate at the desired pressure and discharge rate, if the power requirement and pumping costs are to be kept to a minimum.

Characteristic curves for pumps may be obtained from manufacturers. These curves give information such as efficiencies, power required, and discharge rates at various pressures and speeds of operation. Characteristic curves for three different pumps are shown in Figures 12, 13 and 14.

As an illustration of the use of these curves, assume that a pump is to be selected that will pump 500 gallons per minute against a total head of 100 feet. Figure 12 shows that the 2-inch pump working under these conditions would be operating at an efficiency of 60 percent and would require 21 horsepower. The 3-inch pump, whose characteristics are given in Figure 13, would operate at an efficiency of 78 percent and would require only 16 horsepower. The 6-inch pump, whose characteristics are shown in Figure 14, would operate at an efficiency of 57 percent and would require 22 horsepower. It is obvious that the 3-inch pump would be the best selection to fill this set of requirements, though it would cost more, initially, than the 2-inch pump.

From the curves it may be observed further that the 2-inch pump would be operating near its maximum capacity and could not be used in case the irrigation system should be enlarged. The 3-inch pump, on the other hand, would be reasonably efficient for somewhat higher and lower pumping rates. The 6-inch pump, while usable for small capacities, would operate at extremely low efficiencies.

![Figure 12—Characteristic Curves for a 2-inch centrifugal pump.](image1)

![Figure 13—Characteristic Curves for a 3-inch centrifugal pump.](image2)
**POWER**

The horsepower required to pump a given amount of water can be determined from the following formula:

\[ \text{Horsepower} = \frac{\text{gallons per minute} \times \text{total head (feet)}}{3960 \times \text{pump efficiency}} \]

The head includes the elevation from the water surface to the pump, the height the water must be lifted above the pump, the friction loss in the pipe and pump, and the pressure at the sprinkler, expressed in feet. One pound per square inch of pressure is equivalent to 2.3 feet of head.

Many types of power units may be used to operate irrigation pumps. Gasoline engines are used most commonly for the small irrigation systems. The initial cost is relatively low, they are easily adapted to portable units, and most farmers are familiar with the operation and maintenance of such engines. For continuous duty, the engine should not be operated at more than 75 percent of its maximum capacity.

Diesel and LP gas engines, while they cost somewhat more, use cheaper fuels and may give lower total power costs for large amounts of use per year. For big irrigation systems, where annual fuel costs are high, such engines should be considered.

Electric motors have a high efficiency, require little maintenance, and are easily operated. They are not too well adapted to portable pumping units. Nearly all rural electric power is single phase and the maximum size of motor feasible is approximately 7 ½ horsepower. If larger motors are required, three phase power must be used.

A farm tractor may be used for power but this means that it will not be available for other work during the irrigation period. Also the tractor may not be the right size for the pump. If it is too small it will be overloaded, causing serious damage. If it is larger than necessary, it will not operate as efficiently as an engine of the proper size.

**COST OF IRRIGATION**

The cost of irrigation may be divided into fixed costs and operating costs. These costs vary widely, depending upon the size of the system, its design, and the efficiency of operation.

Fixed costs include depreciation, interest, housing, insurance, taxes, and repairs. Annual depreciation can be figured at 6.5 percent of the first cost (based on a useful life of about 15 years for the equipment). Other fixed costs include interest, 3 percent; housing, insurance and taxes, 1 percent; and repairs, 0.5 percent; making a total of 11 percent of the first cost for all items of fixed cost.

Operating costs include power costs and labor costs. The following may be used as a guide in estimating these costs: Power costs—3¢ per horsepower hour; labor—1 to 2 man hours per acre per irrigation.

Example: If equipment, including a 16-horsepower motor and pump, costing $5,000 is used 360 hours per year in making three irrigations on 50 acres, the costs may be estimated as follows.

- **Annual fixed costs, 11% of $5000**: $550
- **Power, 16 Hp x 360 hrs. = 5760 Hp hrs. @3¢**: $173
- **Labor, 1½ manhours per A per irrigation @$1.00**: $225

**Total Annual Costs**: $948

Annual Cost per acre, $948 ÷ 50 = $18.96

During the fall of 1953, a field survey was made of irrigation systems on a number of farms in south Missouri. Information on costs was obtained from 24 of the irrigators. Many of them were not making full use of their equipment and, as a result, their in-
vestment per acre irrigated was relatively high. (See Table 10.)

The annual costs of irrigation, including fixed and operating costs vary with the amounts of water applied. The amount of irrigation is usually expressed in acre inches. The annual costs of irrigating corn, pasture and forage crops, per acre inch of water applied, are given in Tables 11 and 12.

**TABLE 10 -- COST OF IRRIGATION EQUIPMENT ON 24 FARMS IN SOUTH MISSOURI IN 1953**

<table>
<thead>
<tr>
<th>Acres Irrigated</th>
<th>5-15</th>
<th>16-30</th>
<th>31-50</th>
<th>Over 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of farms in group</td>
<td>8</td>
<td>2</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Average cost of equipment per acre*</td>
<td>$197</td>
<td>$165</td>
<td>$107</td>
<td>$56</td>
</tr>
<tr>
<td>Average acreage irrigated</td>
<td>10</td>
<td>25</td>
<td>44</td>
<td>90</td>
</tr>
<tr>
<td>Percent full use made of equipment (Average for group)</td>
<td>40</td>
<td>41</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>Acres possible to irrigate if full use were made of equipment</td>
<td>25</td>
<td>60</td>
<td>73</td>
<td>100</td>
</tr>
<tr>
<td>Investment per acres if full use had been made of equipment</td>
<td>$80</td>
<td>$68</td>
<td>$64</td>
<td>$50</td>
</tr>
</tbody>
</table>

*These costs do not include the cost of the water supply.

**TABLE 11 -- ANNUAL COST OF IRRIGATING CORN PER ACRE INCH APPLIED, BASED ON 13 CASES IN SOUTH MISSOURI IN 1953**

<table>
<thead>
<tr>
<th>Acre Inches of Water Applied</th>
<th>Less than 100</th>
<th>101 to 300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Costs</td>
<td>$4.00</td>
<td>$2.70</td>
</tr>
<tr>
<td>Labor Costs</td>
<td>1.18</td>
<td>0.94</td>
</tr>
<tr>
<td>Fuel and Oil Costs</td>
<td>0.59</td>
<td>0.52</td>
</tr>
<tr>
<td>Total Costs</td>
<td>5.69</td>
<td>4.16</td>
</tr>
<tr>
<td>Total Costs if full use had been made of equipment</td>
<td>3.44</td>
<td>2.90</td>
</tr>
</tbody>
</table>

**TABLE 12 -- ANNUAL COST OF IRRIGATING PASTURES AND FORAGE CROPS PER ACRE INCH OF WATER APPLIED, BASED ON 19 CASES IN SOUTH MISSOURI IN 1953.**

<table>
<thead>
<tr>
<th>Acre Inches of Water Applied</th>
<th>Less than 100</th>
<th>101 to 300</th>
<th>301 to 500</th>
<th>501 to 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Costs</td>
<td>$4.00</td>
<td>$2.70</td>
<td>$1.15</td>
<td>$0.84</td>
</tr>
<tr>
<td>Labor Costs</td>
<td>0.80</td>
<td>0.45</td>
<td>0.32</td>
<td>0.26</td>
</tr>
<tr>
<td>Fuel and Oil Costs</td>
<td>0.50</td>
<td>0.49</td>
<td>0.43</td>
<td>0.42</td>
</tr>
<tr>
<td>Total Costs</td>
<td>5.30</td>
<td>3.64</td>
<td>1.90</td>
<td>1.52</td>
</tr>
<tr>
<td>Total Costs if full use had been made of equipment</td>
<td>3.10</td>
<td>2.40</td>
<td>1.72</td>
<td>1.50</td>
</tr>
</tbody>
</table>