SUPPLEMENTAL IRRIGATION FOR MISSOURI AND REGIONS OF SIMILAR RAINFALL

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COLLEGE OF ENGINEERING
THE ENGINEERING EXPERIMENT STATION

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SUPPLEMENTAL IRRIGATION
FOR MISSOURI AND REGIONS
OF SIMILAR RAINFALL

by

HARRY RUBEY
Professor of Civil Engineering

Second Revised Edition-1951
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I. IRRIGATION FOR MISSOURI—WHY?

Summary. Most Missourians have experienced the injury to lawns, gardens, or crops resulting from deficient rainfall. These unfortunate occurrences and frustrations usually can be prevented by applying water artificially. The garden hose is a slow, costly, and impractical method for farmers; hence, supplemental irrigation.

The expansion of supplemental irrigation in Missouri will ensure satisfactory crops in those seasons where rainfall is inadequate in amount or distribution through the season, ensure increased quality and quantity of crop yields, permit more use of fertilizers, and permit raising high-value crops which are not being grown intensively in the State at the present time. Irrigation may greatly increase land values as has been the case in older irrigated districts. The diversification of agriculture resulting from irrigation will be helpful. Those who secure large and choice crops by irrigation and use of fertilizer will usually also benefit from higher prices. Doubling of returns, or more, is not uncommon.

As farm income continues at an all-time high level, profitable and permanent improvements on the land, such as supplemental irrigation, provide an excellent investment for surplus funds.

Missouri should capitalize the competitive advantage it possesses over arid regions because irrigation here is less difficult and less expensive, because no costly pioneering settlement is needed, and because better and closer markets are available. The irrigable acreage in Missouri may be larger than that of the average western state. Even though irrigation is optional, its advantages should not be overlooked.

Although supplemental irrigation in humid and sub-humid regions has been practiced in a limited manner since ancient times, it is only in the last generation that it has been extended over several hundred thousand acres east of the one-hundredth meridian of this country and developed on a systematic, economic, and scientific basis. Recent expansion has been rapid and many improvements are available. However, the movement is in its infancy and its literature is scattered.

The scientific irrigation of a garden or small experimental acreage for a few years is an excellent way to become familiar with the value and practice of supplemental irrigation.

1The 1941 Yearbook of Agriculture, pp. 195-6.
It is the purpose of this bulletin to summarize the possibilities of supplemental irrigation for Missouri and regions of similar rainfall, to adapt successful practices elsewhere to Missouri conditions, to warn against pitfalls, and to provide a selected list of annotated references. The author bases his opinions on an interest, including considerable experience, extending over the last thirty-five years.

**Experience Available.** Forty thousand acres were under successful supplemental irrigation in 1940 in the Willamette Valley of Oregon, and plans are now under way to increase this tenfold. The total annual rainfall of 38 inches is about the same as is that of Missouri although only six inches of it falls in the five summer months. Considerable data are available from this region, especially in References\(^2\) 8, 14b, and 16.

More recently the Tennessee Valley Authority and the University System of Georgia have conducted experiments which show supplemental irrigation to be profitable even in that region, where the annual rainfall of more than 50 inches greatly exceeds Missouri's 40 inches (References 10, 14c, 14d, and 14e).

A previous study\(^3\) (Reference 6) found 108 places in Missouri where irrigation has been practiced on a small scale with generally satisfactory results, although often the techniques were crude. Many of the facilities were emergency installations necessitated by the serious droughts of 1934 and 1936, and they were neither planned nor operated so as to secure the best returns.

Satisfactory results, examples of which will be found in References 3, 4, 6, 9, 10, 14a, 14b, 14c, 14d, 14e, 24, 32, and 38, have been obtained in other humid and sub-humid regions.

**Federal Recognition of Need in Connection with Stabilized Agriculture.** *The 1938 Year Book of Agriculture* of the United States Department of Agriculture states:

"In most of the Great Plains livestock runs on native grass pastures or on the open range during most years, and during much of the year. In most of these areas, however, it is essential that other winter feed and emergency supplies be provided for use during much of the winter. In most of these areas it is essential that other winter feed and emergency supplies be provided for use during extremely dry years. Often irrigation offers the only possible method

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\(^2\)These and subsequent references are listed at the end of the bulletin.

\(^3\)It is recommended that the reader examine *Bulletin No. 410* of the University of Missouri Agricultural Experiment Station, *Supplemental Irrigation in Missouri*, by R. P. Beasley, August, 1939. This survey covered much of the non-too-thorough supplemental irrigation existing in Missouri in 1938, and provides useful comments and advice.
of providing such insurance. The recent drought periods on the Great Plains region brought very forcibly to the front the need for this type of supplemental irrigation.

"Stabilization of agriculture in many parts of the United States could be aided greatly by irrigation of these three types: (1) Supplementing the natural precipitation during dry periods in normally humid areas, (2) watering gardens and small forage patches on dry land farms, and (3) supplementing range livestock feed by growing winter and emergency forage crops."

The 1940 Year Book of Agriculture further states:

"Wherever irrigation development on the Great Plains is feasible it should be carried out in a way that will permit an integrated use of irrigated and non-irrigated farming land along with grazing land. Such integration would be most desirable on a farm-unit basis, but where this is not possible integration on an area basis should be planned in order that irrigated land may be used as a winter feed base for livestock.

"The natural forces influencing Great Plains agriculture are so powerful that here, more than anywhere else, public action seems necessary to assist in effecting the adjustments that are needed to stabilize the agriculture of the region. Among such measures is the development of supplemental irrigation."

The Year Book for 1943 to 1947 emphasizes the increasing value and possibilities of irrigation, especially with the best fertilizers, and spacing and strains of plants adapted to irrigation.

**Rainfall Deficiency.** Most crops in Missouri suffer in most years from insufficient rainfall at critical times during their growth. Much of the rainfall is not effective, since less than one-quarter of an inch will not penetrate the ground sufficiently and since a considerable percentage of the heavier rainfall, of three-quarters of an inch or more, may be lost in run-off, which does not soak into the ground.

Table I shows the daily rainfall in central Missouri during the last seventeen summers.* Rainfall of less than 0.25 of an inch is omitted as being generally ineffective. Intervals of ten days or longer without effective rainfall are shown by a heavy black line. Since several such periods occur nearly every summer, the necessity of added water is obvious.

The usual deficiency in summer rainfall causes reduced quality and quantity of crop yield; makes impossible the cultivation of certain crops which especially need adequate water at certain periods of their growth.

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*From the records of the United States Weather Bureau.
Table I. DISTRIBUTION OF RAINFALL IN INCHES AT JEFFERSON CITY, MISSOURI, DURING JUNE, JULY, AND AUGUST FROM 1934 TO 1950 INCLUSIVE.

Rainfalls less than 0.25 of an inch are omitted and periods of ten days or longer without effective rainfall are shown by heavy dark lines.

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growth; and prevents securing the better prices of early, late, or drought markets. Furthermore, since it is thought that many fertilizers tend to “burn out” a crop which is inadequately watered, farmers hesitate to use them.

The Appendix contains an official summary of the most severe summer droughts in Missouri from 1870 to 1947. One-fourth of the 78 years have been very dry and, unfortunately, often close together, causing an accumulation of losses.

Recent Developments. Among the developments of recent years which now make irrigation more attractive in Missouri may be mentioned the following:

1. Improved pumps and power, including portable pumping plants and rural electrification. The Rural Electrification Administration rate in Missouri for irrigation pumping is 2 cents per kilowatt-hour, but few of the power lines can carry a heavy pumping load.

2. Improved portable pipe systems for carrying water from the pump to the land. A single pumping plant with such pipe can be moved to various localities, thus minimizing the investment cost.

3. Improved portable overhead spray and sprinkling systems.

4. The construction of large inexpensive farm ponds that have been and are now being built throughout Missouri.

5. The prospect of better drought predictions from the Weather Bureau. The science of meteorology is constantly developing better predictive information. It may thus aid one to decide whether, and when, to irrigate. Otherwise irrigation may be ruinously delayed in hope of rain that does not come.

6. Realization that supplemental irrigation is growing in popularity, is practical, and is much cheaper than irrigation in arid regions.

7. The continuing interest and experimentation throughout the country as indicated in such publications of the older state and federal governmental agencies as are listed in the references at the end of this bulletin. Fortune magazine featured an article on “Sprinkler Irrigation” in its issue of June, 1950 which predicts extensive expansion in this field.

8. Better markets for early and late crops.

The Demand. As a better agriculture develops with a correspondingly expensive culture, lack of moisture becomes a limiting factor in producing maximum crops.
While supplemental irrigation eventually will become widespread, early operators may profit most, since they will have better and more varied crops than will non-irrigating competitors. They will often raise valuable seed and root-stock crops to sell to drought-stricken neighbors.

The manufacture and installation of equipment for irrigation projects are among the better ways to stabilize industry and to provide self-liquidating investments for many farmers.

Requirements for Success. It is essential that each individual installation for supplemental irrigation be recognized as a separate problem that must be studied in all its aspects and developed in accordance with the best modern practices if maximum success is to be attained. Also, community effort must be organized for irrigation. Halfway measures or procedures will not result satisfactorily.

To assist in such studies, development, and organization, the following description of supplemental irrigation will give an idea of the methods generally applicable in Missouri, but it does not cover all the necessary details and precautions for actual irrigation. Additional information may be secured from the references, from irrigators in older districts, from experience of others in Missouri, and from personal observation.
II. FAVORABLE CONDITIONS NECESSARY

So that irrigation may be profitable, it should be limited to suitable soils, to favorable topography, and to lands where artificial drainage will be unnecessary. There must be an adequate and economical source of water supply and, of course, a satisfactory market.

Maximum crops are obtained with a combination of fertilizers, irrigation, and variety and spacing of plants adapted to irrigation.

Soils. Figure 1 shows the general location of the more extensive bodies of irrigable soils in Missouri. These are often in the bottoms, where adequate water is available. Suitable smaller areas will be found throughout the State. It must be emphasized that good soil is essential.

An ideal soil for irrigation is a medium-textured, highly fertile soil with a subsoil which is only slightly finer-textured than the surface. The most desirable surface textures for irrigation include sandy loam, fine sandy loam, silt loam, and loam. Slightly less desirable surface textures are clay loam, silty clay loam, and loamy sands. The highly organic muck and peat soils can be successfully irrigated.

Extremely sandy soils and those clay soils locally known as gumbo are not generally well adapted to irrigation.

Rice is not damaged by an excess of water, and the level clay soil areas along the larger streams are the most successful rice-producing areas in this region.

Large areas of land, especially on topography which is favorable for irrigation, are underlaid by a dense, impervious, claypan subsoil which restricts drainage. However, under light and controlled applications of water, and with careful attention to drainage, much of this land may be successfully irrigated.

Topography. For the simpler types of surface irrigation, there should be preferably a slight and uniform ground slope of from 2 to 8 inches per 100 feet. Flatter and much steeper slopes can be irrigated by "Special Methods" described later. Sprinkler irrigation can be used on almost all types of topography.
Bottomland along the Missouri and Mississippi rivers that probably includes the most desirable irrigable land, because of favorable soil and topographic conditions. Bottomland along the many smaller streams, particularly in the northwestern part of the state, may be equally favorable, and its distribution can be determined by consulting large scale soil maps.

The upland soils of northwestern Missouri are generally of high fertility and good structure, and irrigation may be feasible where topographic conditions are favorable. Most of the land is rolling and near the larger streams it is hilly.

Fig. 1. General Location of the More Extensive Bodies of Irrigable Soils in Missouri.

For one reason or another parts of these large blocks of land may not be suitable for irrigating.

Many other suitable, but smaller, areas occur in every part of the state.
Saline Soils and Drainage. Where large bodies of adjoining lands are irrigated in the arid West, there frequently develops a water-logged or alkali condition that requires artificial drainage and other expensive relief measures. Circular 707 of the U. S. Department of Agriculture, Saline Soils, September, 1944, states: “On much of the 20,000,000 acres of farm land now irrigated in 19 western states the crop yields are reduced 10 to 20 percent by salinity, or an excess of soluble salts in the soil, commonly called alkali. Salinity causes not only a reduction of crop yields but also, if severe, an outright abandonment of irrigated lands.” These conditions should not be encountered in Missouri, where irrigation will be light, irrigated areas will be relatively small, and heavy rainfall and light evaporation will prevent the accumulation of salts.

It is generally better not to irrigate land if it is anticipated that the water table will rise sufficiently to necessitate expensive drainage.

Water Supply. In most seasons a supply of water sufficient to cover the irrigated area to a depth of several inches will be adequate. If pumping is necessary the lift from the source to the surface of the land, including friction losses, should be less than 50 or 75 feet but may very greatly exceed this with cheap power, for large projects where irrigating costs per acre will be low, for valuable crops, for crops requiring little water, or for other special conditions.

In western arid regions legal difficulties regarding water rights are encountered, but few such difficulties should arise in Missouri, where the water supply is abundant. In most cases a common-sense judgment will suffice as to whether the consumption of certain waters for irrigation will be harmful to other users. So far as is known the question of water rights for irrigation has not yet arisen in this State.

In several states where extensive pumping has been undertaken for irrigation or industrial purposes, the underlying water table has been lowered sufficiently to cause considerable restrictive legislation regarding the use of ground water. Difficulties of this nature are not anticipated in rural Missouri in the near future, if ever.

Markets. Better and closer markets are necessary and, fortunately, more available for Missouri than for most of the arid irrigated regions of the West. Cooperation must be developed among all those interested in irrigation, both for marketing and for perfecting irrigation practices.
III. SOURCES OF WATER SUPPLY

Gravity Supplies. Under a gravity system the water is taken without pumping from a pond, lake, spring, or at a higher elevation along a stream and conveyed to the irrigated lands by gravity in canals, flumes, or pipes. Where gravity supplies are possible they are often the least expensive method of securing the water.

Farm Ponds. Large multiple-purpose farm ponds are now being advocated and built in considerable numbers throughout Missouri. Federal aid will probably continue to be available. It will be possible to irrigate by gravity small areas in the valleys below the ponds and thus to secure irrigation water at low cost without pumping. The methods of constructing and using these ponds are described in Circular No. 482 of the Agricultural Extension Service, University of Missouri, January, 1943 (Reference 11); and Bulletin No. 15 of the Missouri Conservation Commission, September, 1942 (Reference 12).

When a pond is suitably located, it may be possible to use it as a reservoir into which a small low-cost pump continuously discharges sufficient water to permit the irrigation of a much larger area than could be watered from the pond alone. The advantages of this pondage over using a small pump without a reservoir are that rainfall is stored and used, that cheap pumping results from running the pump 24 hours per day (as described later), and that the irrigator does not waste his time in using only the small flow of water discharged by the pump. Such benefits from the farm pond may justify its construction or may suggest a different size and location for the pond.

Pumping from Open Water. Next in economy of securing the water are those supplies pumped from rivers, creeks, or lakes, typical layouts for which are shown in Figs. 2 and 3. Gasoline engines, Diesel engines, and electric motors are available as sources of power. Automobile or tractor engines are often suitable. While any type of pump may be used, centrifugal pumps are best in most cases. A pumping plant may be located permanently or it may be moved from one location to another as circumstances require. It may occasionally be bought second-hand, or rented from construction or well-drilling contractors.

References 2, 4, 6, 13, and 21 to 30 inclusive describe actual pumping installations in some detail, both from open water and from wells. Information regarding costs of pumping is given later in this bulletin.

Pumping from Wells. Somewhat more expensive water supplies are obtained with deep-well turbine and centrifugal pumps from open wells, from drilled wells, from bored wells, or from well points driven into the water-bearing strata. Figures 3 and 4 show typical set-ups of this kind.
Selection of the Pump. A reliable local well driller should be employed to put down the wells. The level of the water is usually lowered materially by pumping and this drawdown must be considered in selecting the pump. Wells should always be tested to determine their drawdown and their potential capacity before selecting the power plant and pump.

The pumping lift used in selecting the pump must include the drawdown of the well, the vertical lift from the normal water surface, the friction loss in all pipes and elbows, the entrance and discharge losses, and the pressure at the nozzles if sprinkling is used. Fig. 2 shows the method of computing the total "head" or lift. For sprinkling systems, nozzle pressures and losses in distribution pipes, must be added. It is helpful if a community can standardize its pumping equipment so that stock parts and service may be available locally.

The selection of the pump and the motor or engine to run it should be left to a reliable pump and irrigation expert in order that a coordinated system of motor or engine, pump, water conveyance, water application, and crop diversification may be secured. It is recommended that a formal agreement be drawn up between the purchaser and the pump company specifically listing the equipment and accessories to be furnished by both parties, the guaranteed performance of the pump, the provision for testing the performance, and the method of payment to the company.

Pumps of smaller capacity running constantly are more economical in first cost than large pumps running intermittently. Furthermore, the drawdown in wells probably will be less for the smaller pump and the total lift of water reduced, thus lowering pumping costs. If electric power is used, the power rate may be lower for the more continuous operation. On the other hand, smaller pumping plants are less efficient, and more irrigating labor is usually required.

These matters are discussed further under the headings "The Economic Size of Project" (page 47) and "Cost of Pumping" (page 48).

If sprinkling is used, provision may be necessary for removing debris and silt from the water since otherwise the nozzles are easily plugged and both bearings and nozzles wear rapidly if silt enters the lines. A suitable screening and desilting box is described on pages 29 and 30 of Reference 44.

City Water Supplies. Cheapest in first cost but most expensive in operating cost are those supplies obtained from city water mains.
Fig. 2. Pumping from Open Water.
The horizontal centrifugal pump is well adapted to pumping from streams, lakes, or from one canal to another. The characteristics of this type of pump are determined largely by the design and speed of the impeller. The manufacturer should have the following information in order to furnish a pump which will give the best efficiency under given conditions:

1. The quantity of water desired in gallons per minute or cubic feet per second.
2. The total "head" or lift in feet.
3. The type of power available and probable speed at which the pump will operate.

The total "lift" or "head" includes not only the actual vertical distance in feet to which water must be lifted as A+B in the sketch but also the friction head in the pipe and pipe fittings.

The size of the suction and discharge pipe must be adapted to the quantity of water to be pumped. The table below indicates the lost head due to friction per 100 feet of length as well as the losses through pipe fittings in terms of equivalent lengths of pipe.

An example: (See sketch)

Let A+B = 20 feet actual head.
Let C+E = 200 feet actual length of 8-inch discharge and suction pipe
D = Medium sweep elbow equivalent to 13.6 feet of 8-inch pipe.
F = Standard elbow equivalent to 21.7 feet of 8-inch pipe.

Compute total head when pump is delivering 1000 gallons per minute.

An 8-inch pipe has 3.02 feet of friction head for 100 feet of length when carrying 1000 gal. per minute. Total friction head in pipe and elbows is (200+13.6+21.7) x .030 or 7.05 ft. Total head is 7.05 feet friction head +20 ft. Actual head = 27.05 feet.

There is a slight additional loss due to the foot valve and other factors.

Friction loss table based on common used pipe.
Fig. 3. Pumping from Open Water and Open Wells.
Pumping from a stream or pond

Garden irrigation can be accomplished by pumping from ponds and streams if the lift is not too great. A small horizontal centrifugal pump set not higher than 10 feet above the water and powered by a gasoline engine in the equipment ordinarily used. Pumps of this type may be had in sizes which will deliver from 30 to 1000 gallons or more per minute.

Pumping from shallow irrigation wells

Along river bottoms where the ground water level is permanently within 10 feet or less from the surface, small irrigation wells may be successfully used for the irrigation of farm gardens. Casings for such wells are ordinarily made from sheet metal slotted to permit water to enter. In some instances old range boilers with the ends cut out are welded together and slotted with a welding torch. Small centrifugal pumps set at the ground surface are quite satisfactory.

Fig 3 Continued.
Fig. 4. Pumping from Wells by Turbine and Propeller Pumps.
TURBINE AND PROPELLER TYPE IRRIGATION PUMPS

The turbine type irrigation pump is adapted to lifting water from wells of various diameters and through various heads from a few feet to several hundred feet. The characteristics of the pump are determined largely by the design of the bowl assembly and the speed of the impeller shaft.

In order to determine the type of pump and design of bowl assembly required for the best efficiency under given conditions the manufacturer should have the following information:

1. The discharge of the well at various stages of "Draw Down". This is determined by a pump test of the well.
2. The diameter of the well casing.
3. The type of power to be used for driving the pump.

Where three phase electrical energy is available, the direct connected motor drive may be used. Other types of drives for the turbine pump are shown.

The propeller type pump is adapted to lifting large volumes of water through low heads. In irrigation practice it is used to deliver water from a stream or lake to a canal at higher level or from a low level canal to one at a higher level. The same types of drives as shown for the turbine are adapted to the propeller pump.

Fig. 4 Continued.
IV. CONVEYANCE OF WATER FROM THE SOURCE TO THE LAND TO BE IRRIGATED

The least expensive method of conveying the water is by permanent or temporary canals or ditches (Figs. 5, 6, 12, 13, 14, and 15), but there is considerable loss of water and loss of the land occupied by the canals or ditches. They are economically constructed by ditchers such as that shown in Figs. 6 and 11, and by other available earth-moving equipment. Modern practice demands plowing in most ditches each year to destroy insects, vermin, and weeds.

Cheaper in land and water use but more expensive in original cost are metal or wooden flumes, the latter being shown in Fig. 7.

The most expensive method of conveyance is in underground pipes, but it has the advantage of minimizing the loss of water. This is an important consideration where water is scarce or expensive, such as that secured from a city main.

One of the important developments of recent years is the use of sixteen- to twenty-foot lengths of light-gage galvanized or aluminum pipe with special couplers which permit the pipe to be quickly assembled, dismantled, and moved to a new location on the surface of the ground. This is especially useful in portable irrigation plants, where the pipe is laid quickly over the ground, then dismantled and moved to another tract of land by one or two men. Figure 8 shows rapid action couplings, several types of which are made by different manufacturers. The same pump and pipe can be used on different parts of a farm or on several different farms, thus minimizing the necessary investment.

Canals and ditches, flumes, and pipes will all necessarily be used to some extent in different installations for supplemental irrigation, but it will be optional throughout most of a particular system to select one or the other of these devices for conveying water.
Irrigation practices vary in different parts of the country and on different farms within a community because of various differences in soil, topography, water supply, crops and customs.

Close growing crops such as alfalfa are irrigated by use of corrugations, borders, border ditches, basins, and contour ditches while row crops are irrigated by furrows and borders. Any one or a combination of several may be best suited to an individual farm.
Fig. 6. Irrigation Ditcher.
Fig. 6 Continued.
TRANSPORTING WATER UNDER LANE AND ACROSS GULLY BY USE OF INVERTED SIPHON AND FLUME

Fig. 7. Wooden Flume.
The buck scraper is a convenient and economical implement for moving earth in land leveling operations. It is particularly useful in filling low spots or removing high ones. When drawn by a team of horses it may be used while water is being applied to borders. After the space between border dikes has been leveled with the float, water may be turned in and the leveling process finished as the low and high spots are revealed. The cutting float is used in somewhat the same manner but is drawn with tractor power and is not adapted to wet leveling.

Fig. 9. Buck Scraper for Land leveling.
Fig. 9 Continued.

BUCK SCRAPER FOR WET AND DRY LEVELING

CUTTING FLOAT

Courtesy of U.S. Farm Security Administration
The so-called irrigation "float or "leveler" is used to produce a uniform, smooth land surface, free from minor irregularities over which water may be evenly distributed. In order to function properly the float should have the following structural features:

1. The length should not be less than 18 feet.
2. At least one cross member should be adjustable to allow for variable soil conditions.
3. The use of divided rollers makes turning easier and reduces draft.

Many types of floats are available, both commercial and home-made. The irregularities produced by farming operations make the use of the float desirable each season on all irrigated fields.

Fig. 10. Float for Land Leveling.

Courtesy of U. S. Farm Security Administration
V. METHODS OF APPLYING WATER TO THE LAND

Many methods of applying water for irrigation, most of which are shown in Figs. 5, and 11 to 21 inclusive, have been developed by long experience, and consequently will give satisfactory results. Departure from these proved techniques should be attempted only by experienced irrigators. The simplest and surest methods for conditions in Missouri are described and illustrated in this chapter. They may be studied in more detail in References 1, 2, 9, 13, 14, 17 to 20 inclusive, 24, and 31 to 45 inclusive. Extensive local experience may develop improvements or adaptations.

Water may be applied to the land by surface methods or by sprinkling, either method being satisfactory if properly used. Sometimes one and sometimes the other method will be chosen.

Where topography and soil are favorable, skilled irrigators are obtainable, no pumping is required, and labor and farm equipment are more available than cash, surface irrigation probably will be the more satisfactory and less expensive method. It will be described first.

**Surface Irrigation**

**Topography and Leveling.** For the simpler types of irrigation, the land should preferably be smooth, with a gentle slope of between 2 and 8 inches per 100 feet. Flatter and much steeper slopes can be irrigated by the “Special Methods” described later in this section.

Only rarely in Missouri will it pay to level* the land extensively as is done generally in arid regions. However, light leveling will usually pay in facilitating the distribution of the water in the fields. It may be inexpensively accomplished with the buck scraper and float of Figs. 9 and 10. Heavy duty equipment will reduce costs on large acreages. The use of a two-way plow will eliminate dead furrows, and ridges in the field.

It is especially necessary that no low spots be left on the heavier soils, where water may stand in pools and “cook” the crop.

On all except the most uniformly sloping land, or under the most favorable conditions, a topographic map, soil classification, and soil profile should be provided for best results. The general layout as shown in Fig. 5 will be worked out in detail on this map. It will ensure a wise choice of irrigating methods, show the actual field layouts, indicate the proper sizes and grades of field ditches and

*As used in irrigation, leveling of land means to smooth it so the water will flow properly—not to make the land level.
The corrugator is a device used to make small furrows or corrugations for conducting irrigation water over the ground surface. Corrugations are particularly adapted to watering grain or hay crops on irregular fields or for new fields which have not been thoroughly leveled and floated.

The runners are commonly made of 4" x 6" material spaced 30 inches apart. This spacing may vary however, depending on the soil and slope of the land.

Fig. 11. Corrugator for Furrowing and Ditcher.
The adjustable crowder is essentially a one-way irrigation ditcher. It is adapted to making various width ditches by adjusting the spreader board between the runner and crowder.

Several furrows are first plowed to loosen the dirt. Then the crowder with the crowder board leaning upward and outward crowds the dirt to one side to form the ditch bank. This operation is then repeated on the opposite side to form the other bank.

**Material Lists**

**Adjustable Crowder**

- 1 pc. 2' x 12' x 11'-0" Runner Board
- 1 pc. 2' x 12' x 6'-0" Crowder Board
- 1 pc. 2' x 6' x 3'-0" Spreader Board
- 1 pc. 2' x 6' x 4'-0" Spreader Adjusted Board
- 1 pc. 1/2' x 2' x 4'-6" Hardwood Handle
- 1 pc. 4' x 6' x 6" - Spreader Block
- 1 pc. 1/8' x 2' x 36" Strap Iron With 1/4" End, 2" Dia. Hitch Ring.
- 2 pcs. 1/8' x 2' x 10" Handle Supports.
- 4 pcs. 1/8' x 1/4' x 5" Spreader Board Ends.
- 1 pc. 12'-0" x 12" Heavy Sheet Metal Cutting Point.
- 3 pcs. 16" x 6" Bolts - Hitch Ring To Runner Bd.
- 3 pcs. 1/4" x 4" Bolts - Crowder Blk To Runner Bd.
- 16 pcs. 1/2" x 22" Button Head Bolts For Hinges.
- 8 pcs. 3/4" x 22" Bolts For Handle Supports.
- 4 pcs. 1/2" x 7" " Spreaders, Block.
- 2 pcs. 1/2" x 7" " " Board Bearings
- 4 pcs. 1/8" x 7" " " Tips.
- 6 pcs. 1/2" x 5" " Spreaders Adj. Bd To Runner.
- 2 pcs. 3" Surface Hinges.

**Configuration**

- 4 pcs. 4'-6" x 6'-0" For Runners
- 3 pcs. 2'-12" x 8'-6" For Cross Boards
- 2 pcs. 4'-4" x 4'-0" For Tongue Connector
- 1 pc. 4'-4" x 2'-0" For Tongue Cross Pc.
- 1 pc. Old Wagon Tongue.
- 1 pc. 1/4" x 2'-12" x 12" Spreader Iron Clevis.
- 1 pc. 1/4" x 1/2" x 5'-0" " Tongue To Cross Pc.
- 2 pcs. 1/2" x 3'-0" " Tongue Braces.
- 2 pcs. 1/4" x 4'-1'-4" " Tongue Connector Ends.
- 1 pc. 1/4" x 8" Bolt - Double Tree To Clevis.
- 2 pcs. 1/4" x 6" " Clevis To Tongue.
- 7 pcs. 1/4" x 6" " Tongue To Cross Tie.
- 1 pc. 1/2" x 8" Lag Screw - Cross Tie To Tongue.
- 2 pcs. 96" x 12" " Connector To Cross Tie Axle.
- 8 pcs. 1/8" x 8" Bolts With Washers - Tongue Connectors To Cross Boards.
- 24 pcs. 1/16" x 8" Cg. Bolts With Hds. In Runners - Cross Boards To Runners.

Fig. 11 Continued.

Courtesy of U. S. Farm Security Administration.
Fig. 12. Furrow Irrigation, with Lath Boxes.
IRRIGATION OF ROW CROPS

Accurate control of flow of irrigation water to row crops is very important under many conditions. The use of check dams, take-out boxes and lath boxes or other forms of spiles permits accurate control of head and saves labor.

The placing of small structures for irrigation of row crops may be explained from the accompanying sketch as follows:

Water enters the field through the field lateral and is shown running from left to right or away from the observer. The secondary ditch or so called "regulation bay" is made either with a plow or some form of ditcher. Small earth dams or checks are placed in "regulation bays" as shown. The spacing depends upon the fall in the field lateral.

1. The metal check dam or canvas dam at "A" is set to raise the level of the water in the field lateral. The by-pass gate in the metal check is opened to allow excess water to pass on down the field lateral.

2. The ditch bank is next cut with a shovel and the take-out box at "B" is placed as shown and well sealed with mud to prevent leakage. The gate in the take-out box is opened to permit water to enter the "regulation bay".

3. Water standing in the "regulation bay" at some given height will form a foam line which permits the setting of the lath boxes or spiles at a given level. A lath box is generally set for each row although where a small head is desired one box may serve two rows. Each lath box should be set as near level as possible and close to the ground in the rows. Each box must be sealed with mud. There is less danger of lath boxes becoming clogged with trash if the head of water in the "regulation bay" is carried above the level of the top of the box.

4. One take-out box will ordinarily serve from 12 to 20 lath boxes. The gate in the take-out box is now opened to allow the desired flow through the lath boxes. The quantity of water flowing through the lath box will depend on the height of water above it. The gate in the check dam is then accurately set to maintain the proper head in the field lateral.

5. After one bay has been set the same process as has been described is repeated in the second bay as shown at "I" and so on until the entire head in the field lateral is used.
Siphon tubes made of light metal or plastics are sometimes used to distribute water from a field lateral to furrows for irrigation of row crops. Some irrigators prefer this method since it is not necessary to cut the ditch bank to place the tubes and the use of a "Regulation Bay" or secondary ditch is not required. It has the disadvantage of being difficult to regulate and if flow in the lateral is interrupted the siphon action in all tubes must be started again.

The siphon action is started as follows:

1. The tube is filled with water by submerging it in the canal.
2. The hand is placed over one end and the tube set in position as shown in the drawings.
3. When the hand is removed flow will start and may be adjusted by raising or lowering the discharge end.
4. The intake end of the tube should be placed far enough under water to eliminate clogging by floating trash.

Fig. 13. Furrow Irrigation, with Syphons.
The border method of irrigation is used for watering close growing crops as small grain and hay on slopes which do not exceed 3 to 4 feet per 100 feet. The dikes which guide the water down the border strip are built with the border drag or with special machines. The dikes are laid out down the steepest slope and the strip must be well leveled if uniform distribution is to result. Most of the leveling is done with the float but may be finished with the buck scraper used after the water is turned in so that the high and low spots may be identified.

Fig. 14. Border Checks. Courtesy of U. S. Farm Security Administration
flumes, outline the areas to be left unirrigated, assist in any necessary leveling, and generally prevent difficulties and save money. Such maps have been used for a generation on the better managed irrigation projects and are especially necessary in a region unaccustomed to irrigation. The map will cost only a few dollars per acre, including expert advice as to the irrigation layout. Examples and specifications for such maps are given on pages 124, 141, and 142 of Reference 2.

**Furrows.** Doubtless the furrow, row, or corrugation method as indicated in Figs. 5, 11, 12, and 13 is best adapted to usual Missouri requirements since it is cheap, requires less experience, will serve all row crops, and can be used for most other field crops. Little leveling of the land is necessary. There is some loss of both land and water in this method. With corn and other crops planted in rows, the rows may serve to form wide furrows which are quite effective. Supply ditches are located either along the upper border of the field or along the ridges. In the latter case, the water runs both ways in the furrows from the ditch. The length of the runs of water should be of the order of 220 feet on fine sand, 330 feet on loam, and 440 feet on clay loam. With longer runs the upper portion is over-watered, the lower end cannot be observed readily, and difficulty is encountered on flat slopes in getting the water to the lower end of the furrows. Even shorter lengths may be better on flat or steep slopes. The amount of water admitted to each furrow will vary with the soil, the slope, and the length of the furrow. Not over 10 gallons per minute is ordinarily used and this will erode usual soils badly on slopes of 24 inches per 100 feet or more. Furrows should generally run down the slope which should preferably be less than 8 inches per 100 feet.

**Checks.** Border checks, such as those shown in Figs. 5 and 14, extend down the natural slope, with low embankments to guide the water. They have been used mainly for alfalfa, clover, and similar crops. The water spreads over the upper portions of these checks, which must be made level transversely, and flows to the lower end. It is well to have the upper 20 or 30 feet of the check level so that the water may spread evenly before starting down the slope, and the slope should not exceed 3 feet per 100 feet.

More leveling is required than for furrow irrigation, and there is the same loss of land and water. Desirable slopes may vary from
IRRIGATION FOR MISSOURI

1½ to 3½ inches per 100 feet on clay soils, to 10 inches per 100 feet on sandy soils, care being taken to avoid steep slopes on heavy soils and flat slopes on sandy soils so that the water will percolate uniformly throughout the length of its run. Checks with usual slopes and flows of water are preferably from 20 to 50 feet wide, and not over 330 feet long on steep slopes of sandy soils or 660 feet on flat slopes of heavy soils. Shorter lengths are better on either lighter or heavier slopes. The longer, wider, and flatter checks require larger flows of water.

Contour checks, which are formed by level low embankments, following the contour of the ground, allow the water to stand in nearly level ponded areas and to seep into the ground.

Level rectangular checks, or basins, Fig. 5, will seldom be used because excessive leveling of the ground is required.

Rice is one of the few crops where ponding of water is essential. Water standing on the heavier soils may harm other crops.

Wild Flooding. Here the water is distributed from ditches along contours, at right angles to contours, along ridges, or along high ground. Although inefficient, it is widely used for other than row crops. Little leveling is necessary.

Because of the lack of guide furrows or embankments for the water used in wild flooding, the supply ditches are spaced from 200 feet apart on slopes of from 5 to 8 feet per 100 feet to 400 feet or more apart on heavy soils with slopes of 1 foot per 100 feet or less.

Contour ditches, shown in Figs. 5 and 15, may be combined with erosion-control terraces, as mentioned in the third section following entitled Disposal of Excess Water.

It is difficult to distribute the water uniformly from the border ditches shown in Fig. 5.

Flooding cannot be successfully used on some soils because of the resulting puddling and crust formation. Cultivation immediately after irrigation, when this is possible, will relieve this difficulty.
The use of contour ditch irrigation is favored in many sections for watering small grain, pasture and hay on irregular slopes or those in excess of 2 or 3 per cent. The success of the system depends upon the care with which the contour laterals are placed. It is customary to build the ditch across the slope with no grade or with less than 1/10 of one foot per 100 feet. In some cases water is diverted to the land directly from the contour ditch. A better method consists of plowing a furrow on the lower side of the contour ditch, throwing the furrow slice uphill. The flow is diverted from the contour ditch to the furrow by means of take-out boxes. Water spilling over the lip of the furrow passes down over the slope in a uniform sheet if the system has been carefully layed out and constructed.

Fig. 15. Contour Ditch Irrigation.
Sub-Irrigation. This method supplies the water laterally and upward from ditches or drain tile below the surface of the ground, and has been used extensively only in a few localities (References 2, 9, and 13).

Special Methods for Steep and Flat Slopes. It must be expected that irrigation will be somewhat more difficult and expensive on the steeper and flatter slopes.

On slopes exceeding 8 inches per 100 feet, up to 10 or more feet per 100 feet, skillful irrigation is required to prevent erosion, especially before the crop is up, and to slow the flow of water so that it will have time to soak into the ground. Small checks or areas, and small quantities of water, are used for flooding. Furrows are usually better than flooding for steep slopes. Where furrows run down the slope, only trickles of water are used in short furrows. Ten gallons per minute of water in a furrow on usual soils will cause serious erosion on slopes of 24 inches per 100 feet. If the furrows follow the contour across the slope, as in some orchard irrigation, the usual 10 gallons per minute may be used in each furrow.

Water does not flow readily over land sloping less than 2 inches per 100 feet. Deeper, smoother, and shorter furrows or rows; contour checks; or level rectangular checks will serve here to apply the water.

Of course, porous hose and sprinklers can be used on both flat and steep slopes.

Disposal of Excess Water. Where surface systems are used, wastage of irrigation water will cost money and labor, and may cause poor drainage, erosion, or other damage. It is usual, but not the best, practice to allow a head of water to run through rows or borders and be wasted at the lower end of a field by running it into road-side ditches or elsewhere.

Care in the handling of irrigation water can result in a saving of both water and labor, and will prevent the common mistake of over-irrigating parts of the crop. A set may be made at “A” in Fig. 16 and rows irrigating from lateral “D” down the slope toward lateral “E”. The waste water is collected above lateral “E” and cut into it at “X”. This excess water is used to irrigate additional rows at “B” and the excess water used at “C”. The same practice may be applied in the case of borders or corrugations.
By careful arrangement of fields and pastures the waste water from one portion of the farm may be economically applied elsewhere. In a few cases the field ditches for irrigation may be used similarly to collect the run-off from heavy rainfall and dispose of it harmlessly, thus preventing erosion of valuable irrigated fields and permitting earlier plowing in the spring.


IRRIGATION BY SPRINKLING

For those not skilled in irrigation, sprinkling offers the surest method of applying water; it may be used on rough topography without leveling and without experienced irrigators; and in some cases, especially where pumping would be required for surface methods, it may be the best and cheapest method. Sprinkling is widely and increasingly used as is indicated by many publications, among the more recent of which are "Sprinkler Irrigation" U. S. Bureau of Reclamation, December, 1949 (Reference 44) and an article on the same subject in the June, 1950 issue of Fortune magazine (Reference 45).

The rotary sprinkler and overhead spray systems, as shown in Figs. 16, 17, 18, and 21 and as described in References 9, 13, 24, and 36 to 45 inclusive are used where pressure is available, usually from pumps. They may consist, at least in part, of permanently placed pipe, but many of the pipes are laid temporarily on or above the surface and can be moved from place to place, thus minimizing the original cost.

Sprinkling must be skillfully designed and operated to meet specific local conditions. The manufacturers of sprinkler equipment are pleased to give design service and estimates, and they should be consulted. References 40, 41, 42, 43, and 44 give some design data.
Fig. 17. Portable Pipe and Rotary Sprinklers.
Fig. 18. Sprinkler Irrigation.
Sprinkling has been improved recently and extended to cover large areas of crops and has become increasingly popular. Since it provides excellent control of water and makes possible the application of smaller quantities, costly leveling on rough ground is unnecessary, canals and ditches are minimized, and both water and land are saved. Added pumping costs are required to maintain pressure of 30 pounds and upwards per square inch at the rotating sprinklers, or somewhat less for spraying.

Recent installation costs for sprinkler systems of from $75 to $125 per acre are common in the Willamette Valley, Oregon, where relatively small acreages of high-priced crops are grown, and where this method of irrigation is popular.
Porous Hose. Porous or eyelet canvas hose, (References 6, 24, 32, and 33) has been used in Michigan for irrigating small areas. Limited experience in Missouri with this method has not been satisfactory, especially with high prices for labor and cotton fabrics. It may be successful here under special conditions. There is little waste of land and water, important items where they are expensive. No leveling of the land is necessary, but extra pumping is needed to maintain pressure of 15 to 20 pounds per square inch in the hose.

Water Requirements

In the majority of cases of supplementing the rainfall in Missouri, enough irrigating water must be applied in a season to the average crop to cover the ground about six inches, or, in other words, each acre of land requires about six acre-inches, or one-half acre-foot of water. This does not include the water lost in evaporation and waste. A wet season may require less water and a dry season more, particularly on porous soils.

The usual irrigation will apply about two inches of water at one time, but the amount required may vary from one to several inches depending on the frequency of irrigation, the type of soil, the moisture content of the soil, the nature of the crop, and the amount of rainfall to be supplemented. A flow of one cubic foot of water per second, which is approximately 450 gallons of water per minute, will cover one acre to a depth of approximately one inch in one hour.

The Irrigating Head. The flow of water used by a farmer in irrigating is known as the irrigating head. It is expressed in cubic feet per second, or in gallons per minute, of water.

The best size of irrigating head for a particular farmer will be large enough to keep a good man occupied with irrigating and associated work, while at the same time not requiring a too large and expensive flow of water. Heads between one-half and two cubic feet per second are generally satisfactory. A good irrigator can handle much more water than a poor irrigator. The greater the care with which the land is smoothed or leveled (not necessary in hose, sprinkling, or spray irrigation), the better the devices for turning the water onto the land, the more porous the soil, and the flatter the slopes, the larger may be the irrigating head. The paragraphs immediately following will be some guide in selecting an appropriate irrigating head for usual conditions. Conveyance losses are excluded.
With furrows, an irrigator can ordinarily handle about one cubic foot of water per second, and will apply two inches of water to about four acres in eight hours. Much smaller irrigating heads may be used, but the irrigator then needs other nearby work to occupy his spare time.

In flooding by the use of border checks, contour checks, level rectangular checks and wild flooding, from one and one-half to several cubic feet of water per second may be handled by one man under average conditions. He will apply two inches of water over six or more acres in eight hours. It is difficult to flood with less than one and one-half cubic feet of water per second unless the checks are made smaller or the field ditches are spaced closer together than usual.

Where pumps are used, and it is desirable to minimize labor, the pump capacity should be sufficient to furnish the heads mentioned above, plus water losses. Smaller pump capacities or irrigating heads make necessary the expenditure of more time and labor in applying the water.

With porous canvas hose, overhead spray, or rotary sprinkler systems, irrigating heads in extreme cases are as little as one-tenth cubic foot per second, and are usually less than one cubic foot per second.

The Economic Size of Project. The following example will illustrate an economic plan to irrigate 160 acres by the furrow, row, corrugation, or sprinkling method. An irrigating head, at the field, of one cubic foot per second will be used. This will apply two inches of water to eight acres in a sixteen-hour day or to 80 acres in ten days. Some authorities recommend two inches of water every seven days in extreme droughts, and this could be accomplished by 24-hour pumping.

However, crops in Missouri generally require only some six inches of irrigation water per season, and 80 acres will be irrigated over some 30 sixteen-hour days scattered through the summer. No loss in conveying the water to the land has been allowed in these figures. The pumping plant and irrigating system will then be idle for the remainder of the season. By diversification of the crops so that their need for water comes at different times, perhaps double the foregoing acreage, that is, 160 acres, may be irrigated in 60 days of sixteen-hour pumping. Even more acres could be irrigated or greater depths of water could be applied by pumping more days or for 24-hour periods, and there would still be some time for moving and maintaining the equipment.
It thus becomes apparent that under the conditions stated above, and if an irrigating head of one cubic foot per second is suitable for the project, maximum economy of cost and labor will result on a diversified project of some 160 acres.

By a similar line of reasoning, for sprinkling or for flooding with an irrigating head of two cubic feet per second, a tract of the order of 320 acres will be a desirable size of project.

For greatest economy where only smaller acreages and flows of water are available, irrigating heads of from one-tenth cubic foot per second upward may be indicated, and it is under such circumstances that porous hose, sprinkling, and furrows are most useful. However, the total cost, including labor, per acre for irrigating on these smaller projects will be greater than on the larger projects, unless labor is available for the smaller projects at little or no cost.

In organizing the larger and more economical projects, it may not be necessary to limit the equipment to one farm, since a portable plant may serve several irrigators.
VI. COSTS AND PROFITS

Since each supplemental irrigation development is highly individualized, it is impossible to give generally applicable data on costs and profits. Each project must be planned and estimated separately.

Cost of Pumping. Figure 20 shows the amount of fuel or the cost of electricity for pumping water to various heights sufficient to cover an acre to a depth of one inch, or what is known as an acre-inch of water. One acre-inch equals 3630 cubic feet or 27,154 gallons.

It should be noted that unit costs may be prohibitive for high lifts and for small amounts of water pumped per season, and that the slightly lower unit costs obtained with smaller pumps will be offset by greater labor costs for irrigating with small flows of water.

A modern electric motor and a 3- to 4-inch centrifugal pump for furnishing one cubic foot per second (450 gallons per minute) of water against usual pumping lifts (including the vertical lift, drawdown, and all friction losses) will cost several hundred dollars, excluding wiring and installation. A gasoline motor and pump will cost more, and a Diesel unit still more, although the latter will be more economical in fuel consumption and repairs if used for heavy pumping over many seasons. The Diesel is too expensive in first cost for limited pumping. Of course, no original cost for the power unit will be incurred where the regular farm tractor is used.

First cost, maintenance, and attendance are a minimum for the newer grease-lubricated, ball-bearing, built-in-motor-type pumping unit.

When pumping is used, it is especially desirable to diversify the crops so that the demands for irrigation will occur at different times. This permits the pumping plant, pipe, and equipment to be operated over more days and minimizes the initial cost per acre and the charge for interest, depreciation, taxes, and insurance.

Total Irrigating Costs. So far we have considered the power cost of pumping only, not the total cost of irrigation. Much the larger part of surface irrigation expense is incurred for labor and farm equipment usage which may not involve a cash outlay. On the other hand, sprinkling systems require less labor and more cash. The costs given subsequently are total irrigating costs, including pumping or other methods of securing the water and including interest and depreciation on the original cost or investment.

As has been stated heretofore, each project must be planned and estimated individually, and consequently it is impossible to give cost figures that will suit a particular project. However, the following will furnish a rough idea of 1950 costs of irrigation to those not
Fig. 20. Pumping Costs.
A POWER REQUIREMENT CHART FOR PUMPING

By means of this chart it is possible to determine power requirements, fuel consumption, and electrical energy costs at various pumping plant efficiencies and at various lifts.

At "A" at the upper left is the scale of lifts from 0 to 80 feet. The lift must include not only static head but friction and velocity heads as well.

At "B", upper center, overall plant efficiencies are represented. Overall efficiencies of small, irrigation pumping plants run from 40% to 60%.

On the line X-X' is shown horse power values when pumping 1000 gallons per minute.

In the center of the chart, at "C", the fuel consumption of various types of engines is represented.

The approximate number of horse power hours developed per gallon of fuel for various types of engines is given below:

<table>
<thead>
<tr>
<th>Type of Engine</th>
<th>Horse Power Hours Per Gallon of Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline engines in poor repair</td>
<td>6 to 7</td>
</tr>
<tr>
<td>Gasoline engines in good repair</td>
<td>8 to 9-1/2</td>
</tr>
<tr>
<td>Engines using fuel, oil, semi-Diesel, etc.</td>
<td>9 to 11</td>
</tr>
<tr>
<td>High speed Diesel</td>
<td>11 to 14.5</td>
</tr>
</tbody>
</table>

At the lower part of the chart "E" is given the power cost in cents per acre-inch of water pumped at various rates in cents per kilowatt hour.

The line Y-Y' at the bottom of the chart represents the power required in kilowatts, when pumping 1000 gallons per minute.

Use of the Chart

The use of the chart is shown by the following example:

The lift of a given irrigation pump is 45 feet; the overall efficiency of the plant is estimated at 50%. What will be the horse power required to pump 1000 gallons per minute? How many gallons of fuel will be required to pump an acre-inch of water, using fuel oil in an engine other than Diesel? What would be the cost in cents per acre-inch, using electricity at 2¢ per kilowatt?

Starting at the upper left hand margin locate the lift, 45 feet at point "A". Follow to the right until the 50% efficiency line is intersected at point "B".

From the point "B" follow downward until the line X-X' is intersected. It will be noted that 23 horse power is required to pump 1000 gallons per minute. Continue downward until the line representing 10 horse power hours per gallon is intersected at "C". From the point "C" follow to the left to the point "D" which shows that 1.0 gallon of fuel will be required to pump an acre-inch of water.

If the cost in cents per acre-inch is required, with electrical energy costing 2¢ per kilowatt hour, follow downward from point "C" to point "E" on the diagonal line showing 2¢ cost. From point "E" follow to the left to point "F" which shows the cost of pumping one acre-inch of water under the given conditions to be 15 cents.

If the electrical load is required, follow downward from "E" to point "G" which shows a value of 17¢.

If lifts other than those shown are to be used, certain allowances must be made. If values for a 100 foot lift are desired, those given for a 50 foot lift may be doubled, etc.

Fig. 20 Continued.
familiar with such practices. Costs for a particular case may be considerably lower or higher. It must be reiterated that costs per acre are generally much higher on small areas than on large areas.

Much of the total cost of irrigating is for labor and may not require a cash outlay.

**ORIGINAL COST**

The average original cost of installing supplemental irrigation on a well-planned project in Missouri may be in the neighborhood of $50 to $100 per acre.

**TOTAL ANNUAL COSTS**

The annual cost of keeping the irrigation installation "ready to serve", whether used or not, consists of interest, depreciation, etc. of 7 to 10 percent annually of the original cost, or from $3.50 to $10 per acre per year. This may be considered in the nature of an "insurance premium" for protection against droughts and against decreased yields in dry periods occurring at critical stages of growth of the crops.

Each year that irrigation is used, and this will be most years for most crops, the total cost for each acre, including the annual costs of the preceding paragraph, may be from $12 to $20.

Irrigation costs throughout the arid West are much greater than those for Missouri. Furthermore, transportation, land values, and taxes are correspondingly higher.

**Comparative Costs of Surface Versus Sprinkler Supplemental Irrigation.** While each installation for irrigation differs from others and even though prices and costs rise and fall, a fairly reliable comparison of costs is possible as between these two methods of irrigating. For this purpose a typical eighty-acre tract is shown on Fig. 21 as it would be irrigated by semiportable sprinkling, and the cost of sprinkling is compared with that of surface irrigation on the same tract of land. In this example, as is often the case, the total annual costs for each of the methods will be about the same ($18 per acre), and the decision of which to use will depend largely on the other factors discussed in the following several paragraphs. It must be reiterated that each irrigation installation is different and the cost comparison may be quite different on another tract of land.

*Modified to Missouri conditions from Reference 44.*
IRRIGATION FOR MISSOURI.

ORIGINAL COSTS

In this example, and usually, it will be noted that sprinkling costs more to install at the beginning than do surface methods.

**ORIGINAL COSTS FOR SPRINKLING EIGHTY ACRES**

- Underground mains ............................................................ $4,000
- Laterals ................................................................. 2,500
- Electric motor, pump, and accessories ........................... 1,500
- $100 per acre ......................................................... Total 8,000

**ORIGINAL COSTS FOR SURFACE IRRIGATION OF EIGHTY ACRES**

- Leveling (smoothing rather than heavy grading) ............. $2,000
- Field ditch .............................................................. 1,000
- Drainage ditch .......................................................... 100
- Combination concrete checks and drops ......................... 100
- Turnouts ................................................................. 100
- Concrete checks .......................................................... 100
- Irrigation spiles or tubes ........................................... 100
- 15” concrete pipe for roadways .................................... 100
- Electric Motor, pump, and accessories ......................... 1,200
- $60 per acre ......................................................... Total 4,800

**TOTAL ANNUAL COSTS**

It will be noted in the following tabulation, as is usually true, that the costs per year for interest, depreciation, and power are higher for sprinkling while the labor costs for applying water and for maintenance are higher for surface irrigation unless topography and soil are unusually adapted to the latter. Interest is charged at 5%. There is little depreciation when surface methods are used. Power costs are of course higher for sprinkling.

<table>
<thead>
<tr>
<th></th>
<th>Sprinkling</th>
<th>Surface Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest and depreciation</td>
<td>$10</td>
<td>$4</td>
</tr>
<tr>
<td>Labor applying water</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Power</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Maintenance</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>18</strong></td>
<td><strong>13</strong></td>
</tr>
</tbody>
</table>

Most of the original cost and of the annual cost for sprinkling requires a cash outlay while most of the same costs for surface irrigation consist of labor and the usage of farm equipment which may require relatively little cash outlay. On the other hand, labor must be more experienced and skilled in surface irrigation than is necessary for sprinkling.

In Missouri, pumping usually will be required for both methods. The pumping for sprinkling will be against higher pressures and the power costs somewhat greater. However, the original cost of the pump and its accessories will not be proportionately increased. Since a pump usually must be furnished and operated for both surface and sprinkler irrigation, this fact somewhat favors the latter.
Fig. 21. Example of an 80-acre Semi-portable Rotary Sprinkler System.
Profits. Such references as 14a, 14b, 14c, 14d, 14e, 16, 24, 38, and 39, give actual cost and profit data for supplementary irrigation similar to those quoted later, but it is not often possible to find data that can be transferred with confidence to a new situation. Often these references include pictures of irrigated and unirrigated yields; a striking evidence of the benefits of irrigation. Costs and crop prices are both higher now than in the past.

The following quotation from Reference 8 summarizes 30 years of experience in western Oregon, where the summer rainfall is less than that of Missouri, and gives the average net profit for many trials covering ten crops over a thirty-year period. The projects were reasonably well-chosen, well-planned, and well-operated.

“The study of supplemental irrigation on sub-humid lands over a 30-year period leads to the conviction that light irrigation would be valuable drought insurance throughout much of the so-called humid and sub-humid areas of the country.

“Water lifted 25 feet has netted a profit of $1.50 for each acre-inch or each dollar of total annual cost.”

Under the cheaper prices of the past and generally favorable conditions, the total cost of irrigating in Oregon was about $1.00 per acre-inch of water applied.

A few cases of controlled experiments by the Tennessee Valley Authority (References 10 and 14c) are quoted below as illustrating recent, although limited, experience in a region with a rainfall heavier than that of Missouri.

“Snap Beans—1938

<table>
<thead>
<tr>
<th>Variety and Treatment</th>
<th>Total Water Applied</th>
<th>Yield in Pounds</th>
<th>Market</th>
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</thead>
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<td></td>
<td>10/3 10/7 10/13 10/18</td>
<td>Lbs.</td>
<td>Bushels Per Acre</td>
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<td>Asgrow Black Valentine, Irrigated</td>
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<td>293.6</td>
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<td>As. Bl. Val.</td>
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<td>61.0</td>
<td>162.4</td>
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<tr>
<td>Unirrigated As. Stringless, Irrigated</td>
<td>4.6 9.5 28.5 16.5</td>
<td>58.5</td>
<td>136.0</td>
</tr>
</tbody>
</table>
"Comparison of Irrigated and Unirrigated Turnips and Spinach—1940

<table>
<thead>
<tr>
<th>Crop and Treatment</th>
<th>Acres Grown</th>
<th>Crop Value</th>
<th>Cost of Harvesting</th>
<th>Total Net Returns</th>
<th>Returns Per Acre</th>
<th>Cost of Irrigation Per Acre</th>
<th>Net Returns Per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turnips, Irrigated</td>
<td>1.7</td>
<td>$336.00</td>
<td>$168.00</td>
<td>$168.00</td>
<td>$98.80</td>
<td>$4.80</td>
<td>$94.00</td>
</tr>
<tr>
<td>Turnips, Unirrigated</td>
<td>0.2</td>
<td>4.00</td>
<td>2.00</td>
<td>2.00</td>
<td>10.00</td>
<td>---</td>
<td>10.00</td>
</tr>
<tr>
<td>Spinach, Irrigated</td>
<td>4.0</td>
<td>161.70</td>
<td>69.30</td>
<td>92.40</td>
<td>23.10</td>
<td>4.80</td>
<td>18.30</td>
</tr>
</tbody>
</table>
| Spinach, Unirrigated| 0.5         | No spinach worth harvesting | None

"The cost of irrigation in the above table includes actual labor, depreciation on equipment, and interest on investment. The irrigated crops, because of the increased growth due to added moisture, were harvested earlier and were placed on the market while prices were highest. The unirrigated crops made very little growth before frost set in.

"Comparison of Irrigated and Unirrigated Irish Potatoes—1940

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Acres Grown</th>
<th>Total Returns</th>
<th>Cost of Irrigation Per Acre</th>
<th>Net Returns Per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>0.55</td>
<td>$130.27</td>
<td>$11.10</td>
<td>$228.90</td>
</tr>
<tr>
<td>Unirrigated</td>
<td>0.11</td>
<td>14.59</td>
<td>132.64</td>
<td>132.64</td>
</tr>
</tbody>
</table>

"The 1941 growing season in the Tennessee Valley was unusual in that two very severe droughts occurred, one during the spring months followed by heavy rains in July, and the other during August which continued through the entire fall.

"Comparison of Irrigated and Nonirrigated Sweet Potatoes—1941

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Acres Grown</th>
<th>Yield Per Acre</th>
<th>Unit Price</th>
<th>Gross Return Per Acre</th>
<th>Irrigating Cost Per Acre</th>
<th>Net Return Per Acre Less Cost of Irrigating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>1</td>
<td>266.6 bu.</td>
<td>$0.90</td>
<td>$122.40</td>
<td>$13.16</td>
<td>$218.62</td>
</tr>
<tr>
<td>Nonirrigated</td>
<td>2</td>
<td>50 bu.</td>
<td>$0.85</td>
<td>$76.78</td>
<td>$14.28</td>
<td>$62.50</td>
</tr>
</tbody>
</table>

"Irrigated versus Nonirrigated Truck Crops—1941

<table>
<thead>
<tr>
<th>Crop</th>
<th>Treatment</th>
<th>Acreage</th>
<th>Yield (bushels)</th>
<th>Unit Price</th>
<th>Gross Return Per Acre</th>
<th>Irrigating Cost Per Acre</th>
<th>Net Return Per Acre Less Cost of Irrigating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irish Potatoes</td>
<td>Irrigated</td>
<td>0.50</td>
<td>136. 11.</td>
<td>$0.90</td>
<td>$122.40</td>
<td>$13.16</td>
<td>$218.62</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>Nonirrigated</td>
<td>0.05</td>
<td>1.04</td>
<td>$1.00</td>
<td>$73.29</td>
<td>$150.00</td>
<td>$270.00</td>
</tr>
<tr>
<td>Sweet Potatoes</td>
<td>Irrigated</td>
<td>0.25</td>
<td>1.51</td>
<td>$1.00</td>
<td>$293.00</td>
<td>$150.00</td>
<td>$270.00</td>
</tr>
<tr>
<td>Non-irrigated</td>
<td>Nonirrigated</td>
<td>0.036</td>
<td>0.35</td>
<td>$0.025</td>
<td>$73.29</td>
<td>$150.00</td>
<td>$279.78</td>
</tr>
</tbody>
</table>
“Results of Irrigated Pasture on Burton Farm—1941

Approximately 23 acres of pasture seeded with a mixture of Ladino clover and Balboa rye grass was irrigated during the 1941 season. A 2-acre plot was fenced off across one end of the field. This plot was not irrigated and was used as a check against the irrigated pasture. The seeding and management of the two plots were the same. The pasture season was extremely dry and all the vegetation on the 2-acre check plot died out and furnished no pasture at all. The table gives the results obtained from the irrigated plot.

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total no. of cow pasture days</td>
<td>$848.70</td>
</tr>
<tr>
<td>Length of pasture season (days)</td>
<td>$210</td>
</tr>
<tr>
<td>Cost of irrigating</td>
<td>$248.34</td>
</tr>
<tr>
<td>Aver. no. cows pastured per acre</td>
<td>1.73</td>
</tr>
<tr>
<td>Value of one cow pasture day</td>
<td>$0.10</td>
</tr>
<tr>
<td>Net value of pasture per acre</td>
<td>$26.10</td>
</tr>
</tbody>
</table>

The amount of 10 cents per cow pasture day as used in the preceding table was taken as the cost of additional feed which the cow would have required if she had not been on pasture. The rotation method of grazing was used on all of these pastures, and the forage was not grazed shorter than 1.5 to 2 inches.”

Reference 14c reports this TVA experiment as continued through 1945.

The following quotation from Reference 14a summarizes the experience with irrigation on rice soils in Arkansas:

“Fertilized and unfertilized plots of rice soil, Crowley silt loam, planted to cotton, soybeans, or corn were irrigated and the yields obtained compared with the yields from nonirrigated fertilized plots, and unfertilized plots. Lespedeza for hay and seed was grown without fertilization on irrigated and nonirrigated plots.

In the preliminary experiments irrigation was practiced at definite intervals without consideration of the percentage of moisture in the soil. Rainfall occurring in some years from one to 5 days before the irrigation was made offset any practical value of the water added, so another method to determine the time for irrigation was adopted. Water was applied in the latter experiments whenever results of a moisture determination on the soil approximated 15 per cent or less.

Highly significant increases in the average yield resulted from irrigations of cotton at stated intervals. Application of fertilizer also produced highly significant increases in yield of seed cotton. The largest yield in these experiments was obtained from the combination of application of fertilizer with subsequent irrigation.

Increased yields of seed cotton were obtained in all experiments when the irrigation was based on the percentage of soil
moisture. Increases in yields in these experiments were associated with the need of the plants for water during periods of drought. In 1941 irrigation was not necessary until the latter part of August. Rowden 41A, a medium early maturing variety, was nearly mature, and the average increase in yield resulting from irrigation was only 47 pounds of seed cotton per acre. Stoneville 2-B and Coker Wilds 12, later maturing varieties, gave larger yields of 265 and 163 pounds of seed cotton per acre, respectively. Very little rain fell in 1943 during June, July, and August, and it was necessary to make seven irrigations between June 22 and August 29. The yields for Rowden 41A, Stoneville 2-B, and Coker Wilds 12 for the irrigated soil were 1,036, 1,197, and 1,020 pounds per acre, respectively. The increases associated with irrigation were 650, 761, and 708 pounds of seed cotton per acre, respectively.

"Irrigation of soybeans at stated intervals resulted in significantly larger yields of beans. Increases in yields of beans obtained in all experiments when fertilizer was applied were not significant. The results from irrigation of soybeans when the soil moisture content approximated 15 per cent are similar to those for cotton. The differences in yields of hay were not significant in 1941 because the soybeans were cut for hay within a few days after irrigation. However, in 1943 large increases in yields of hay were associated with the frequent irrigations necessary to maintain the soil moisture content above 15 per cent. The average increased yields of hay in that year for Arksoy, Red Tanner, and Mamloxi varieties were 1.34, 1.16, and 1.46 tons per acre, respectively.

"Increases in yields of beans were very similar to those for hay. In 1943 when seven irrigations were necessary, increased yields of 17.3, 8.4, and 13.8 bushels per acre were obtained from the Arksoy, Red Tanner, and Mamloxi varieties, respectively. A small increase, which was not significant, was obtained when corn, which was not fertilized, was irrigated irrespective of soil moisture. The increase resulting from irrigation under the same conditions of corn which had previously been fertilized, although highly significant, was small.

"Irrigation of corn when the soil moisture was less than 15 per cent resulted in large increases in yield in 1944, a year in which the rainfall during the growing season was very limited. A yield of only 10.8 bushels was obtained without irrigation, whereas a yield of 36.5 bushels per acre was associated with two applications of water, each of 2 acre-inches. When irrigation was applied to plots having two plants per hill, the acre yield was 47.7 bushels. This was an increase of 36.9 bushels over the nonirrigated plot having one plant per hill.
"Application of a complete fertilizer also increased yields, especially when irrigation was done. The average yields with irrigation were 47.0 bushels per acre with one plant per hill and 60.1 bushels with two plants per hill. Without irrigation the yield was only 16.7 bushels.

"Lespedeza hay and seed yields were increased as a result of irrigation when the soil moisture approximated 15 per cent or less.

"As with the other crops—cotton, soybeans, and corn—the increases in yield of lespedeza hay were associated with the plants' need for water, or in other words, the number of irrigations necessary. In 1941 the only irrigation required was made on June 20. Following this there was sufficient moisture until the hay was harvested in August, so irrigation was unnecessary. The increase in yield was only 0.17 ton per acre. In 1942 four irrigations were necessary for hay production and the increase in yield associated with irrigation was 0.98 ton. In 1943 six irrigations of lespedeza resulted in a total yield of 4.72 tons per acre, an increase of 3.13 tons associated with irrigation.

"Increases in yields of lespedeza seed were similar to those for hay. An increase of 112 pounds of seed per acre was associated with four irrigations in 1942, and 351 pounds of seed per acre with seven irrigations in 1943."

In the Yearbook of Agriculture, 1943-1947, an example is given by L. M. Ware of the Alabama Agricultural Experiment Station. Sweet corn failed completely in a field at Auburn, when no commercial fertilizer was used, he reported in 1945; the plant food in the soil was inadequate to support corn production. But when a commercial fertilizer was added, a yield of corn valued at $153 an acre was obtained. When a commercial fertilizer was added and the corn irrigated, a crop was produced that had a value of $253 an acre. When a commercial fertilizer and manure were added, the crop was valued at $349.50 an acre. When a commercial fertilizer and manure were added and the corn was irrigated, a crop was produced that had a value of $553 an acre. When commercial fertilizer and manure were added, a crop of vetch was turned, and the corn was irrigated, a yield was produced that had a value of $699.50. Each fertility factor artificially helped to provide more nearly the optimum conditions for corn production. The effect on the yield of corn was cumulative. When all factors were supplied, a yield of 13,845 pounds of marketable green corn was produced.

Many other examples of the increased quality and quantity of yields are given in the References and elsewhere. Further improvement will be obtained as culture, fertilization, spacing, and strains are adapted to irrigation and as further experience becomes available.
VII. ORGANIZATION FOR IRRIGATION DEVELOPMENT

Cooperation and Advice. Successful irrigation throughout the arid West has involved blocks of land of from several thousand to over a million acres. In most cases the development has been supervised by federal or state governments, or by large private corporations, and the whole undertaking, including the actual irrigating and farming, has naturally attained the efficiency which characterizes larger enterprises. On the contrary, supplemental irrigation in Missouri will comprise relatively small isolated areas; nevertheless, it will be essential to develop similar efficiencies. Under these conditions it is also essential that the group action characteristic of older successful irrigated districts be encouraged in Missouri so that these cooperative practices may be established here, and extended and modified to fit the local situation.

The individual farmer must have advice, since he is not skilled in the complexities of planning necessary for modern irrigation, since he will attempt to economize too much in the first cost of installation and in the operation of irrigating, since he may not put in the crop so that it can be quickly and properly irrigated, and since he is likely to abandon irrigation if a few years of satisfactory rainfall occur. Irrigation once abandoned, the next dry spell finds the irrigator unprepared.

A Single Plant for Several Farms. In cases where portable pumping plants are practicable, a group of farmers may own such a plant, as well as the necessary portable pipe, and may arrange among themselves for the irrigation of such parts of their farms as may be agreed upon.

Alternatively, a farmer or a well-drilling contractor may secure this equipment and rent it to others, preferably operating the plant and directing the distribution of the water because of his experience in these matters. This is analogous to present rental practices with tractors, combines, and other farm machinery.

Promotion. It is expected that in some cases a promoter will control large tracts of land which he will sub-divide and sell in smaller tracts, including an agreement to provide water under certain conditions. This procedure is a common one on large projects in arid regions.
Since pump, pipe, and sprinkler companies are interested in selling their equipment, and power companies in selling power, they doubtless will be interested in developing supplemental irrigation.

**Subsidies.** It is possible that subsidies for supplemental irrigation may become available from state and federal agencies. The availability of competent advice and the establishment of experimental and demonstration plots under such auspices are "musts" for successful irrigation.

**General Requirements.** In order to establish irrigation on a large-scale and successful basis in Missouri and regions of similar rainfall, much promotional work and cooperation among those interested will be essential. The development of procedures that have secured results in arid regions will have to be modified and extended to suit local conditions.

It is hoped that this bulletin will provide an informational basis that will encourage such development.
VIII. CONCLUSIONS

Most of the conclusions may be inferred from the preceding pages of this bulletin, but a brief summary is presented here.

Supplemental irrigation has been practiced satisfactorily in various portions of the United States since 1900, and the procedures and techniques have been developed sufficiently to justify expansion and to ensure corresponding results in Missouri and regions of similar rainfall. Vegetables and truck crops, orchards, small fruits, corn, alfalfa, clover, and most crops all give promise of profit under proper irrigation and market conditions. Rice must be raised in standing water but most other crops may be irrigated either by sprinkling or by surface methods.

Irrigation in Missouri should be viewed partly as insurance against droughts and partly as a method of increasing the yield and value of crops. It will provide a self-liquidating type of investment for the surplus funds now in the hands of farmers.

Advantages. The eight points previously enumerated on page 9 make irrigation in Missouri more promising than in the past.

Missouri possesses a competitive advantage for irrigation over many western arid regions because rainfall supplies most of the needed water; because water-right, water-table, and drainage problems are at a minimum; because the country is settled and developed; and because it has larger and closer markets.

Requirements. Supplemental irrigation should be used only on good soil, with proper slopes, with good drainage, and with a reasonable irrigating cost. It should also be directed toward satisfactory markets, performed under experienced direction, and installed permanently. It does not pay to irrigate for a dry year or two and then abandon the plan because of inadequate planning or because of a few years of relatively satisfactory rainfall.

Experience shows definitely that use of proper fertilizers generally must go hand in hand with irrigation if the maximum returns are to be obtained. Also, strains and spacing of plants adapted to irrigation must be used, and crop rotation is frequently advisable.

It is necessary that controlled experiments and demonstrations be established in Missouri and continued without interruption over wet and dry years sufficiently to accumulate local data for irrigation and to demonstrate good practices. A program similar to that described in References 8, 10, and 14c will suffice.
The advancement of supplemental irrigation will best be accomplished through the interest and efforts of groups and organizations, as has been the case in most older successful irrigation developments, rather than by individuals. Modified organizational procedures that will give benefits comparable to those that have been realized in arid regions must be established in humid and sub-humid regions.

**Larger Acreages Desirable.** Larger acreages will generally cost less per acre for irrigating than will smaller acreages. Because of the greater community interest in common problems among more people on larger projects, these larger acreages generally will produce more marketable and more profitable crops. Smaller acreages may be irrigated profitably under special conditions and by careful planning.

**Competent Advice Necessary.** The irrigating head, the capacity of the pump and the distributing system, economy of pumping, the economical use of labor for irrigation, the amount of acreage to be irrigated, and the diversification of crops must conform to a balanced plan if a particular project is to furnish economical irrigation. The interest of organized groups is necessary. This type of informed procedure has nearly always been the basis for successful irrigation. Otherwise, the irrigation may be abandoned, with consequent loss and dissatisfaction, as has happened often before in the older irrigated districts.

Many questions arise in the mind of one contemplating irrigation for the first time. Competent advice must be secured before any extensive development is started. Irrigation is undertaken to secure a profit, and poor planning or operation will reduce profits, sometimes to the vanishing point. Irrigation practices are now standardized and established. Permanent and satisfactory results cannot be secured by hap-hazard, unplanned, and temporary developments.

The 1943-47 Year Book of Agriculture states that “The irrigation farmer should not be content with using water to eliminate the hazard of drought. . . . On any farm, at whatever level of soil fertility, maximum plant growth cannot be obtained if moisture is a limiting factor. Where moisture and plant nutrients are supplied in adequate amounts, the highest production will be obtained only when there are enough plants to utilize fully the space available for growth. It is only when the best combination of the various practices is obtained that the farmer may expect a maximum yield.”
APPENDIX

Major Summer Droughts in Missouri from 1870 to 1947 Inclusive

A consideration of the data in this Appendix on major summer droughts and crop yields and of that on normal summer dry spells in Table I on page 8 will indicate the distribution of rainfall over many years. It should aid in deciding what crops, and what varieties, will benefit most from irrigation.

The subsequent quotation describing severe summer droughts in Missouri is extracted from the Annual Summary of Climatological Data, U. S. Department of Agriculture, Weather Bureau, Missouri Section, for 1930, Vol. 34, No. 13, pages 54-55. The quotation does not include those dry years since 1930, notably 1934, 1936, and 1944. In interpreting the following tabulation one should note that the figures are averages and that half of the State consequently received less than these amounts. Because there is often extreme variation in the rainfall throughout Missouri, these figures do not show conditions in the worst districts. It should be further noted that several dry years often occur close together, thus placing an unusual strain on the farmer.

To the rainfall data in Table II two columns showing the annual percentage yields per acre of Missouri's major irrigable crops have been added at the right of the tabulation. The figures show the drought yield as a percentage of the yield of a good, but not the best, year. They are taken from the Bulletin, Missouri Department of Agriculture, Vol. 40, December 31, 1942. Where dry years are not accompanied by poor yields, it will be found that adequate rainfall occurred during the critical growing period. Again, these are averages for the State, and half of the farms produced less. Irrigation should increase these yields considerably above the 100 percent figure.

"For a more detailed comparison the percentages of normal rainfall for March to May, June, July, and August in Missouri for all droughts back to 1870 are presented for review:
<table>
<thead>
<tr>
<th>Year</th>
<th>March to May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>Corn</th>
<th>All Tame Hay</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
<td>59</td>
<td>78</td>
<td>24</td>
<td>55</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>1918</td>
<td>108</td>
<td>67</td>
<td>42</td>
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</tr>
<tr>
<td>1916</td>
<td>98</td>
<td>143</td>
<td>30</td>
<td>105</td>
<td>65</td>
<td>105</td>
</tr>
<tr>
<td>1914</td>
<td>64</td>
<td>48</td>
<td>67</td>
<td>114</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>1913</td>
<td>94</td>
<td>53</td>
<td>78</td>
<td>28</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>1911</td>
<td>73</td>
<td>37</td>
<td>100</td>
<td>110</td>
<td>85</td>
<td>45</td>
</tr>
<tr>
<td>1901</td>
<td>70</td>
<td>43</td>
<td>50</td>
<td>50</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>1894</td>
<td>88</td>
<td>80</td>
<td>62</td>
<td>41</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>1890</td>
<td>80</td>
<td>54</td>
<td>74</td>
<td>135</td>
<td>90</td>
<td>90</td>
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<td>78</td>
<td>91</td>
<td>58</td>
<td>89</td>
<td>70</td>
<td>90</td>
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<tr>
<td>1886</td>
<td>76</td>
<td>108</td>
<td>34</td>
<td>72</td>
<td>75</td>
<td>90</td>
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<td>1881</td>
<td>80</td>
<td>114</td>
<td>38</td>
<td>42</td>
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<td>95</td>
</tr>
<tr>
<td>1874</td>
<td>87</td>
<td>60</td>
<td>63</td>
<td>64</td>
<td>45</td>
<td>85</td>
</tr>
<tr>
<td>1873</td>
<td>103</td>
<td>68</td>
<td>62</td>
<td>45</td>
<td>65</td>
<td>90</td>
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<td>1871</td>
<td>62</td>
<td>70</td>
<td>103</td>
<td>81</td>
<td>105</td>
<td>90</td>
</tr>
<tr>
<td>1870</td>
<td>58</td>
<td>84</td>
<td>64</td>
<td>180</td>
<td>95</td>
<td>70</td>
</tr>
</tbody>
</table>

“In 1930, state-wide and severe, but less severe in extreme southwest and in much of the northwest section. July and August combined brought the driest 80-day period since the same period in 1881.

“In 1918, all State, June to first part of August, but only severe in July, materially reducing the corn yield.

“In 1916, confined to July and first part of August, most of State; modified northern half but continued southern half State through August.

“In 1914, May to mid-August, but not markedly severe except on some of the higher lands.

“In 1913, severe and general latter part of April to mid-September but with considerable relief in July. The hay crop suffered the most.

“In 1911, May 9th to July 11th, excessive heat and severe drought most of the State. Rain came in to save the corn.

“In 1901, state-wide and severe; the outstanding drought and heat of record and perhaps of a century or more. Drought began December, 1900, and continued through to September, 1901; 26 inches of water in 13 months. Nearly total failures of all crops except wheat.

“In 1894, July to August northern and central sections; July along the western border and generally south of the Missouri River; and June to November in most of the Ozark plateau and southeastern lowlands.

“In 1890, local drought spring to July; severe only over rather a limited area across the central part of the State from west to east.

“In 1887, quite general but severe only during July, resulting in the usual marked reduction in corn yields.

“In 1886, general and rather severe in July and August, affecting the corn yields especially on the higher lands; the main bottom lands did not suffer much.

“In 1874, the cut in the State corn yields indicated that this drought was severe June, July and through August; embracing practically all State July and August.

“In 1873, rather local and during July over western section and during August over all eastern parts.

“In 1871, general and severe spring drought. July rain saved the corn crop. July and October the only months with normal or above rainfall. Steadily dry year, total only 29.52 inches, next driest year to 1901.
"In 1870, January to July seven months brought only 50 per cent of the normal rainfall. Splendid rains coming early in August saved the corn crop. The year was dry, total yearly amount 30.44, the third driest year of record, August and October being the only two months with good rains."

A Dry Year

A picture of Missouri in a dry year is here extracted from the July, 1930, Climatological Data for Missouri of the United States Weather Bureau:

"Severe heat and drought were the outstanding features of July, 1930, over every part of Missouri.

"At the close of July the total rainfall for the crop season, beginning with April, was only 10.26 inches, about 60% of the normal. Only one station, Joplin, in the extreme southwest, received more than three inches as monthly total; and but 11 stations got two inches or more, while 33 stations had 0.50 inch or less, and two stations, Lucerne and St. Charles, received but a trace for the entire month.

"Grain crops harvested before July gave good yields. Hay was short. At the end of July the corn crop was nearly a total failure, as well as meadows, pastures, and most forage. Cowpeas and soybeans were holding up. Apples and grapes were deteriorating rapidly. Forest trees were dying. Wells and creeks were dry, and the main rivers were as low as ever known. Many localities were suffering because of the lack of water for domestic and livestock purposes."

Harmful droughts occurred more recently in 1934, 1936, 1937, 1939, 1940, 1941, 1944, 1945, and 1947. The relation between rainfall at Jefferson City and crop yields for Missouri is given in Table III.

<table>
<thead>
<tr>
<th>Year</th>
<th>Rainfall</th>
<th>Annual Crop Yields</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>March to May</td>
<td>June</td>
</tr>
<tr>
<td>1947</td>
<td>118</td>
<td>180</td>
</tr>
<tr>
<td>1945</td>
<td>164</td>
<td>171</td>
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<tr>
<td>1944</td>
<td>138</td>
<td>25</td>
</tr>
<tr>
<td>1941</td>
<td>79</td>
<td>98</td>
</tr>
<tr>
<td>1940</td>
<td>68</td>
<td>115</td>
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<td>1939</td>
<td>113</td>
<td>105</td>
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<td>1937</td>
<td>92</td>
<td>119</td>
</tr>
<tr>
<td>1936</td>
<td>50</td>
<td>05</td>
</tr>
<tr>
<td>1934</td>
<td>45</td>
<td>72</td>
</tr>
</tbody>
</table>

Climatic Cycles

Much thought has been given to the interesting question of cycles of wet and dry years, but as yet meteorologists are unwilling to predict the future from such studies. It is reiterated that irrigation must be undertaken on a long-time basis, and that the possible future occurrence of several years of fairly satisfactory rainfall should not control the decision to install irrigation facilities.
GLOSSARY

Units of Measurement
A gallon of water contains 231 cubic inches and weighs 8.35 pounds.
A cubic foot of water contains 7.48 gallons and weighs 62.5 pounds.
An acre-foot of water is the amount necessary to form a layer of water one foot deep over one acre. It is equal to 43,560 cubic feet, or 326,000 gallons.
An acre-inch equals 1/12 of an acre-foot. It is equal to 3630 cubic feet, or 27,154 gallons.
One pound of pressure is created by a column of water 2.3 feet high. As an example, if the pressure gauge on a pump reads 10 pounds, then the pump is working against friction and lifting equivalent to a straight vertical lift of 23 feet of water.

Flows of Water
One cubic foot per second equals 450 gallons per minute or 0.646 million gallons per 24 hours.
One cubic foot per second, or 450 gallons per minute, will furnish one acre-inch per hour; that is, it will cover one acre to a depth of one inch in one hour.

Pump and Electric Motor Calculations

Theoretical Water Horsepower of a Pump = \frac{\text{Gallons per Minute X Pressure at Pump in Feet}}{3960}

Actual Horsepower Applied to Pump = \frac{\text{Theoretical Horsepower}}{\text{Pump Efficiency}}

Kilowatt Input = \frac{\text{Gallons per Minute X Pressure at Pump in Feet}}{5308 \times \text{Pump Efficiency} \times \text{Motor Efficiency}}

One acre-inch of water lifted one foot requires approximately one-sixth kilowatt hours of electrical energy. An average pump and motor efficiency of 50 per cent is assumed.
One horsepower = 746 watts.
One kilowatt = one and one-third horsepower.
One kilowatt = 1000 watts.
Single-stage centrifugal pumps under ordinary conditions vary in efficiency from 50 to 80 per cent. These figures should be expressed as decimals from 0.50 to 0.80 when they are used in the foregoing formulas. For belt-driven pumps, add 5 to 10 per cent to the actual power requirements to provide for belt slippage.
SELECTED AND ANNOTATED REFERENCES

General

   This bulletin contains suggestions for assisting such farmers to master the details of preparing land for irrigation, laying out and building farm ditches, and handling the water supply so as to assure the best results. Although old, this bulletin is still useful.

   This is one of a three-volume set of authoritative books which completely cover the subject. Although now somewhat old and applicable largely to California conditions, the detailed discussion of fundamentals and practical details is unexcelled.

   Statistical review of irrigated acreage in humid regions of the United States. Included are irrigation results, surface irrigation, orchard irrigation by means of eyelet hose, and adaptation of practice to meet special conditions.

   A summary of crops responding to supplemental irrigation in humid areas, chief advantages of supplemental irrigation, methods of irrigation, types of pumps, electric motors, pertinent results, and bibliography.

   Brief survey of present status of supplementary irrigation in Eastern United States, and derivation of precipitation and irrigation indexes.

   This bulletin describes in some detail most of the supplemental irrigation in Missouri in 1938, and provides useful comments and advice. It must be remembered that these irrigators pioneered as individuals without organized assistance and consequently could not secure the best results.

   Outline of methods developed by the Soil Conservation Service for determining irrigation needs in Michigan on the basis of normal rainfall and severity of drought.

IRRIGATION FOR MISSOURI.

Review of practice of supplemental irrigation in that part of western Oregon where annual rainfall is from 38 inches upward while rainfall for the three summer months is under two inches. Mr. Powers gives a more detailed, but earlier, statement in the Oregon State College Agricultural Experiment Station. Bulletin No. 392, June 1932.


This bulletin supersedes Farmers' Bulletin No. 1529, Spray Irrigation in the Eastern States, and No. 1635, Surface Irrigation in the Eastern States, and includes material on sub-irrigation and the new type of portable sprinkling irrigation.


In the Tennessee Valley the yearly rainfall is approximately 50 inches. However, it is often unevenly distributed, resulting in periods of drought during the growing season, a condition which greatly reduces the crop yield.


Methods of constructing and using ponds, including brief statement of use for irrigation.


Methods of constructing and using ponds.


A portion of this recent book is devoted to developing, conveying, and applying water for irrigation, especially by the sprinkling method and by portable pipes.


This bulletin describes an early mistake in applying water, followed by very successful results.


A summary of results.

14c. Truck and Pasture Irrigation. Tennessee Valley Authority.

Published in January, 1946, this supplements item 10 above.

A brief statement of irrigation possibilities in Georgia where the rainfall is heavy, averaging 50 inches, but where major and minor drought periods occur in the spring, late summer, and fall months.

14e. Results of Irrigation Research in Georgia - Parts I & II, John R. Carreker and W. J. Liddree, Agricultural Engineering, June and July, 1948.

A statement of results so far attained and of research necessary for supplemental irrigation in Georgia where rainfall is heavy, averaging 50 inches, but major and minor drought occurs in spring, late summer, and fall.


A general textbook treatment of irrigation.


An excellent up-to-date summary of present practices, including a chapter on irrigation in humid climates.

See also references 17, 24, 35, 44, and 45.

Special Crops


A brief summary of British practice.


This bulletin gives results of a 10-year experiment with loganberries, evergreen blackberries, red raspberries, black raspberries, and strawberries as to yields, quality, costs of production and harvesting, gross income, and net profits. Conducted in the Willamette Valley, Oregon, where the average rainfall for five summer months is six inches.


A discussion of the type of irrigation suitable for the growing of alfalfa. This bulletin is a revision of Farmers' Bulletin No. 865, Irrigation of Alfalfa.


The profits from an irrigated orchard are dependent upon a uniform distribution of water on the surface and a proper control of soil moisture from the root zone of the trees. Many failures are directly traceable to insufficiency of water supply or the manner in which it is controlled and distributed. This bulletin is a revision of Farmers' Bulletin No. 882; Irrigation of Orchards.

Methods of wild flooding, the border and corrugation methods in irrigating small grain, are discussed in this bulletin, as are also the preparation of the land for irrigation, the proper time to apply the water, and the quantity of water required. This bulletin is a revision of Farmers' Bulletin No. 863, Irrigation of Grain.

See also references 4, 6, 8, 9, 10, 14a, 14b, 14c, and 24.

Pumping


The purpose of this bulletin is to guide aright those interested in pumping from wells for irrigation by making available the most essential details pertaining to well construction and the selection, installation, and operation of pumping plants. Now superseded by Reference 25.


Installation of 80 deep-well-turbine pump units on the San Carlos Project of U. S. Indian Irrigation Service, near Coolidge. Purchase of pumps, pump specifications, efficiency evaluation, shop and field tests, pump houses and controls, and installation results are discussed.


A fairly thorough discussion of the design of the pumping plant including gasoline, Diesel, and electric power; power drives; suction pumping; and discharge. Examples are given.


This reference and additional articles on pages 304, 357-9 deal with pumping water and with growing cantaloupes, tomatoes, strawberries, and other crops under irrigation in Iowa. Experience with a homemade porous-hose installation and with sprinkling are described.


Throughout the United States are many farms which could be irrigated by pumping from either ponds, streams, or farm wells. This bulletin is intended to furnish owners or operators of such farms with information that will give costs and enable them to determine whether soil and water suitable for irrigation are available and what kind of irrigation plant and equipment will be most satisfactory for the purpose. This bulletin supersedes Farmers' Bulletin No. 1404, Pumping from Wells and Irrigation.


Illustrated description of pumping equipment installed near Duncan, Arizona. Eight engines include four different models of Cummins Diesels. All pumps are Johnston turbines equipped with Johnson gear head.

Large quantities of water are stored beneath the surface of the ground in layers of saturated sand and gravel. The most feasible method of recovering this water is by pumping from wells, and for this purpose wells capable of supplying large quantities of water at a reasonable cost are required. This bulletin furnishes comprehensive information concerning these wells.


Experience of Etiwanda Water Company, California, in providing emergency water supply for orange growers. Deep well pumping by Washington gas engines offered the solution to a serious problem.


Less than one-third of the valley is under cultivation. At the present time there are about 60 Diesel powered pumping plants in the valley. Diesels are largely of the slow speed type, for the most part being single-cylinder units of 60 to 75 horse power, and are found sufficient for irrigating an average of 80 acres.


This bulletin is intended to furnish information necessary in keeping small irrigation pumping plants, indispensable during the present emergency, operating at high efficiency.


See also references 2, 4, 13, 36, and 38.

**Surface Irrigation**


The corrugation method of irrigation is more adapted for application of water to steep or irregular slopes, or where the family is required to use a small stream of water, or for new land which has not yet been thoroughly prepared for irrigation. It may sometimes be used to aid in conjunction with the border method of irrigation as a means of spreading water evenly over the border strip. This bulletin describes the most approved practices to be followed when the corrugation method is employed and points out its advantages and limitations. Though old, this bulletin is still useful.


This is a discussion of the need for irrigation in Michigan, the use of porous hose for distributing the water, the improved quality and quantity of crops, the selection of pumps and equipment, and the cost of irrigating. It appears to have been applied on areas of ten acres or less.

Distribution of irrigation water by means of porous canvas pipe 2½ inches in diameter laid along the center row of truck gardens.


The border method of irrigation described in this bulletin, while but one of the several methods followed in western states, is well adapted to a variety of soils and crops and is growing rapidly in public favor.


This is an excellent set of whiteprint plans drawn in perspective projection giving detailed instructions for distributing irrigating water. Many of these plans are used as illustrations in the foregoing pages.

See also references 1, 2, 9, 17 to 20 inclusive, and 24.

Sprinkling


Description of portable Perrot-Deutz Diesel pump for spray irrigation from open bodies of water; data on overhead irrigation practice.


Report on the University of California experimental study of irrigation sprinkling with portable systems. This study gives uniformity of distribution, evaporation losses, hydraulic characteristics, costs, and ground conditions for success in a sprinkler system.


Review of expansion of overhead irrigation of vegetable crops in Western Oregon during recent years. Examples of use and cost.


Engineering and cost data on the construction and operation of portable rotary sprinkler systems of irrigation.


Uniformity of application of water by sprinkling systems. Spacing, arrangement, and operation of irrigation sprinklers so that there can be absorption without run-off.


Describes low-cost portable systems with respect to (1) the hydraulic characteristics of rotating sprinklers, (2) loss of water by evaporation, and (3) the hydraulic characteristics of sprinkler lines.


   The latest general and fundamental treatment of the subject.

   An up-to-date popular treatment.

   See also references 9, 13, 14b, 14c, and 24.