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SUPPLEMENTAL IRRIGATION

FOR

MISSOURI AND REGIONS

OF SIMILAR RAINFALL

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Third Revised Edition-1953

COLLEGE OF ENGINEERING
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THE UNIVERSITY OF MISSOURI BULLETIN

ENGINEERING EXPERIMENT STATION BULLETIN NO. 33

SUPPLEMENTAL IRRIGATION

FOR

MISSOURI AND REGIONS OF SIMILAR RAINFALL

by

HARRY RUBEY

Professor of Civil Engineering

Third Revised Edition-1953

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Preface

Government support for many farm products has reduced the danger of low prices. The best farm practices as developed by research and experiment are passed on to farmers by experts in each county and otherwise, and the efficient producer is ensured a profit except for dry weather. Irrigation is the only remedy for this remaining hazard and the only way to prevent the savings and plans of years from being wiped out by serious droughts. The major droughts of 1934 and 1936 in the Corn Belt and the Great Plains and the drought of 1952 in the South and New England, with some fourteen states declared disaster areas, prove that most localities in the humid East are subject to drought as a disaster. Often drought years are close together and accumulate disastrous results. In addition, the less obvious droughts reduce crop yields, eat away profits year after year, prevent the intensive culture that assures maximum yields and profits in all years, and disturb the permanent farm and livestock program.

Much progress has been made since this Bulletin first appeared in 1945, particularly in recognizing that the adoption of supplemental irrigation for maximum profit requires a higher type of culture than did non-irrigated farming. On the other hand, it returns large profits (often over 100% on the annual cost of irrigation) in crop yields and also gives assurance that the permanent farm and livestock program will continue without interruption from dry weather of long or short duration.

Irrigation is not suitable everywhere. It must be carefully planned, it should not be undertaken in a halfhearted manner, and this Bulletin aims to give the latest viewpoints and practices.

The material presented has been gathered from many sources, persons, and experiences. So far as possible credit is given in the text. Especial encouragement and aid for this edition have been received from Col. C. R. Pettis, hydrologist, of Des Moines, Iowa. He has kindly read the manuscript and his suggestions have been most helpful.

The Author.

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I. SUPPLEMENTAL IRRIGATION—WHY?

Summary. The supplemental irrigation advocated in this Bulletin is not simply adding a little water to ordinary farming operations—but rather adopting a new high type of insured crop culture which differs considerably from the usual practice without irrigation. It is not recommended in general that irrigation be undertaken unless on a thorough and permanent basis accompanied by a high type of culture including intensive fertilization, close spacing of plants, careful selection of strains adapted to irrigation, etc. It should be used most years on most crops—not only in droughts, and preparation must be made before the crops are planted.

The expansion of supplemental irrigation in Missouri will ensure satisfactory crops in those seasons when 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. Preparing the land for surface irrigation often aids drainage and facilitates early spring plowing. 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 on the competitive advantage it possesses over arid regions[1] 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.

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 some two and one-half million acres east of the one-hundredth meridian of this country and developed on a systematic, economic, and scientific basis. While written primarily for Missouri, this Bulletin applies in general to the humid East of the United States. Recent expansion has been rapid and many improvements are available. However, the movement is in its infancy and its literature is scattered.

[1]The 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. Sixty thousand acres were under successful supplemental irrigation in 1946 in the Willamette Valley of Oregon, and plans are now under way to increase this greatly. The total annual rainfall of 38 inches is about the same as 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, 16, 20b, and 20c.

More recently the Tennessee Valley Authority, the University System of Georgia, and agencies of adjoining states 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, 14e, 14p, and 20a).

One hundred and twenty-five thousand areas of corn are being irrigated successfully in Eastern Nebraska.

A previous study (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, 14j, 20d, 20e, 20f, 20g, 20h, 24, 32, and 38, have been obtained in other humid and sub-humid regions. Over a million acres of rice and citrus land are irrigated in the wet South.

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 of pro-

[2]These and subsequent references are listed at the end of the bulletin.

viding 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 3-month summer periods.* 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

*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 1952 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. Irrigation would be needed during these dry periods at a "rule of thumb" rate of 1" per week, or a little more, and occasionally at other times.

	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952
June 1		0.30									0.29					1.28			
2		0.50												1.22					
3	0.39	0.60		0.40		0.40										.48	1.34		
4				0.62	0.25					0.41									
5				0.42						0.37				1.20					.30
6										1.14						.71			
7		0.81			0.60		1.54		0.39	0.63		1.20		0.28				.44	
8									0.54	0.54		2.11							
9				1.98		0.39		0.55		0.46	0.45					.32		.37	
10	1.80			1.10	0.49	0.40		0.80	0.62			0.67					.70		
11	0.41	1.04			2.10		1.10												
12						0.60	0.54		1.65									1.33	
13											0.30				.39				
14																.44			
15					0.34								0.80		.60	.71		.29	
16										0.70					.46				
17		1.09		0.30								0.68							
18												0.25			1.15				
19		0.34							0.26				1.18						
20						0.90												.72	
21		0.60				0.65			0.40					0.35	2.37	1.08			
22						0.68			0.56	0.29					1.28				.83
23										0.53								.28	
24							1.25	0.30								.27		1.96	
25														1.73	.45	1.24			
26		0.62			0.27				3.63			0.74		0.26	1.31	.36		1.22	
27									0.45					0.66		.26			
28								1.98				0.81			.66			.58	
29		1.05											0.81	0.57				.58	
30															.56			.51	
July 1			0.25									1.70		0.91					
2		0.40																	
3								0.25											
4										0.27							.26	1.22	
5									2.58	0.61				0.36					
6														0.25				1.63	
7																			
8					0.62														.60
9						0.45		0.84				0.67						.36	
10									3.20							.80		.33	
11				0.30				3.30							.74				
12											0.43							.68	
13		0.34																	
14					0.82														.39
15																			.54
16																.93			
17				0.43	0.90					0.30						.44	1.10		
18					1.04												.40		
19				0.80						0.67							1.37		
20															1.10				
21																			
22		0.65													.60				
23		0.43														.69			
24																			
25										0.37									
26											1.70				1.95				.52
27												0.80	1.58						
28	0.96				0.30								1.84						
29																			
30										0.87	1.20				.28				.48
31																			
Aug. 1	0.25									1.66							.68		
2				0.40		0.35					1.33								
3									0.45										
4				0.64					1.10			0.45			.56				
5									0.51										
6							1.30						2.02						.49
7																			
8			2.82														.60		
9							3.00			0.74							.34	.42	1.92
10		0.46					0.43												
11	0.40						0.46									1.27			1.34
12	1.05					0.40													.65
13		0.25											1.75			.90	1.86		
14													2.83			.34			.75
15									0.81				4.77	0.34				1.97	
16	1.35		0.56														1.18		
17	1.30			0.65		0.66													
18						0.63	2.20												.41
19		0.52						0.40				0.47							
20																1.53			
21	1.57				0.66						1.21								2.04
22				0.25							0.51								
23						0.55			0.60		0.26								
24													0.51						
25								2.15					0.42	0.25					
26								0.90			1.65							.28	
27							0.40								1.19			.92	
28					0.30										.50	1.14		1.60	
29																		.36	
30																	.63		
31																			

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 intensively enough for maximum yields.

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. This may aid one to decide whether, and when, to irrigate. Otherwise irrigation may be ruinously delayed in hope of rain that does not come or harmfully used before a rain.

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. It is now realized that losses due to interruption of the farm and livestock program may be greater than losses due to diminished crops.

8. Better markets for early and late crops. Often drainage is improved and will permit early spring plowing.

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.

An Example of Irrigated Crop Planning. With sufficient water for growing corn assured by supplemental irrigation, the reasonable yield to be expected from a suitable field should be estimated (over 100 bushels per acre), the strain best suited to irrigation selected, the plant population determined with a Plants-Bushel Ratio (PBR) of 100 or less, and fertilizer and manure (barnyard or green) applied under expert advice in proportion to the expected yield. This type of procedure on 125,000 acres of corn under supplemental irrigation in Eastern Nebraska is producing high yields. It illustrates the planning of a high type of culture under supplemental irrigation which is suitable to many crops.

Mention should be made of irrigated pastures (References 20d and 20e) which have proven so helpful on livestock farms and which illustrate a kind of self-harvested crop that reduces the labor required. In Missouri, with non-irrigated pasture almost burned up in 1952, irrigated pasture is supporting from 1½ to 2 mature cattle per acre.

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.

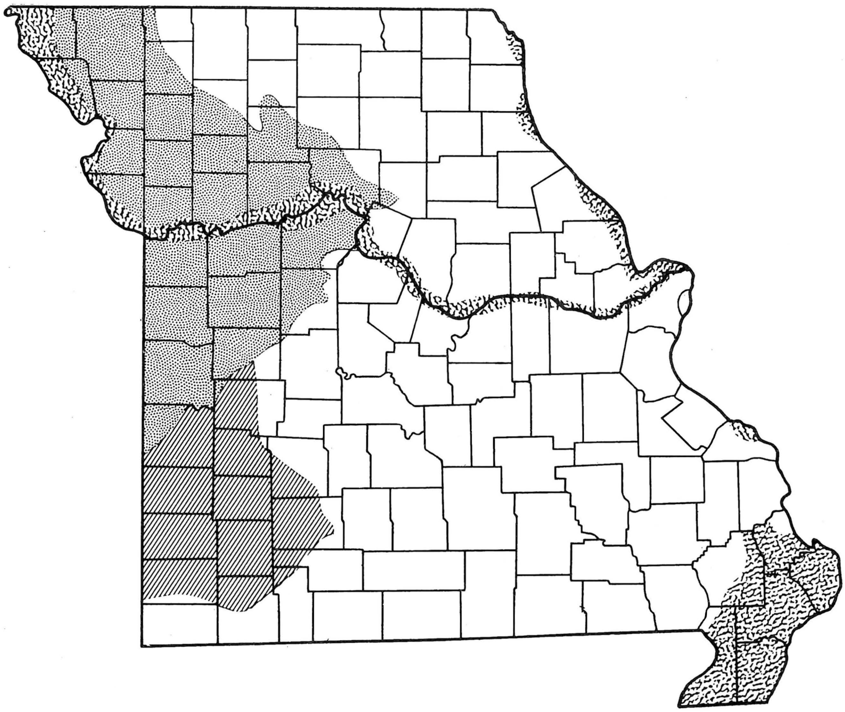
An ideal soil for irrigation is a medium-textured, highly fertile soil with a subsoil which is only slightly finer-textured than the surface. The most desirable surface textures for irrigation include sandy loam, fine sandy loam, silt loam, and loam. Slightly less desirable surface textures are clay 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 water, 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 will be feasible. Most of the land is rolling and near the larger streams it is hilly, often necessitating sprinking.

The southwestern prairie section of Missouri includes extensive areas of brown limestone soils and is well suited for the irrigation of orchards, small fruit, and pastures. Higher winds and lower humidity, especially in late summer, add to the need for supplemental irrigation. Ground water in this area is limited and generally surface water supplies will be used.

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 the humid East, where irrigation will be light, irrigated areas will be relatively small, heavy rainfall and light evaporation will prevent the accumulation of salts, and ground water levels are not rising.

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 75 or 100 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 30a 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. The deeper and larger wells are often gravel packed.

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 49).

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.

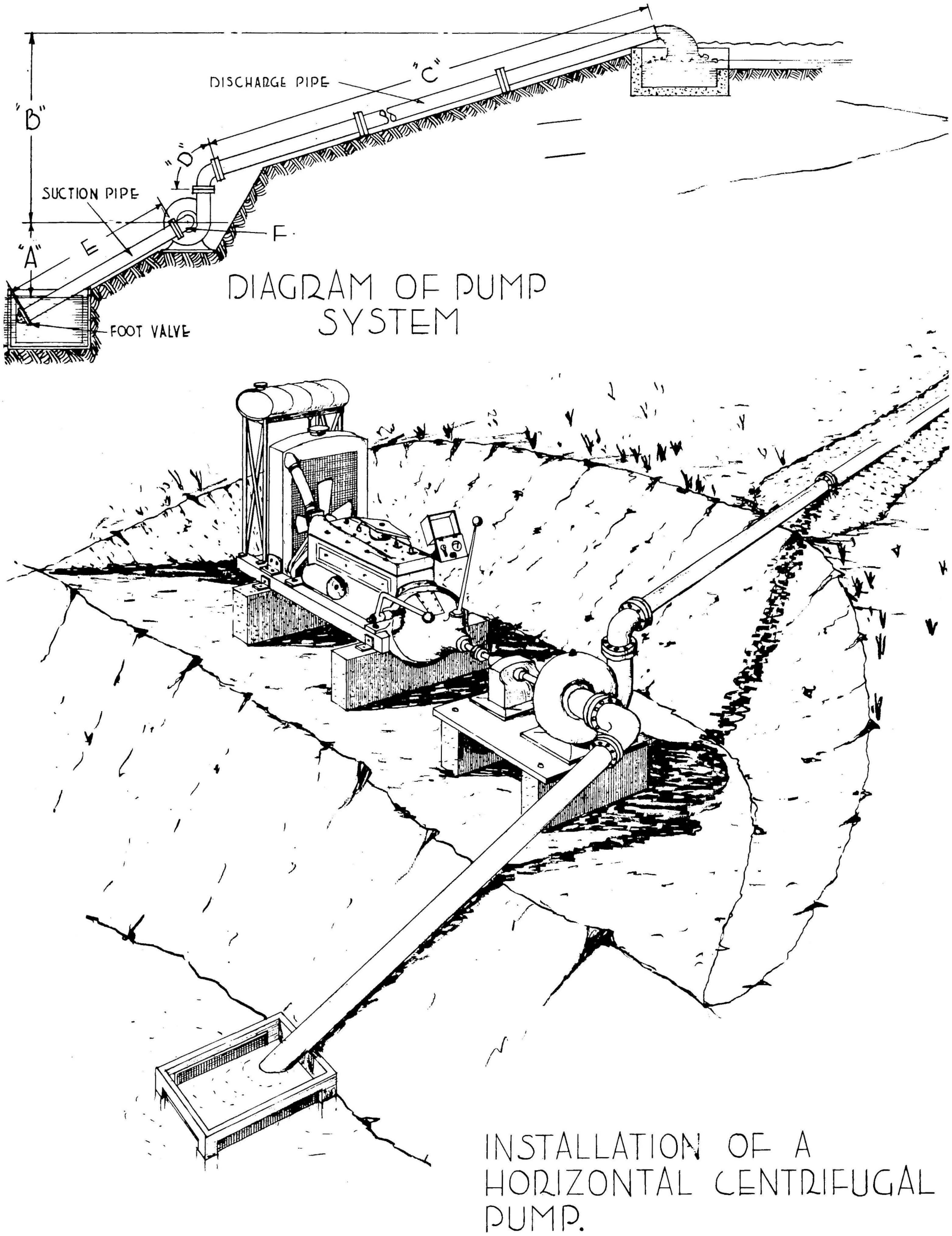
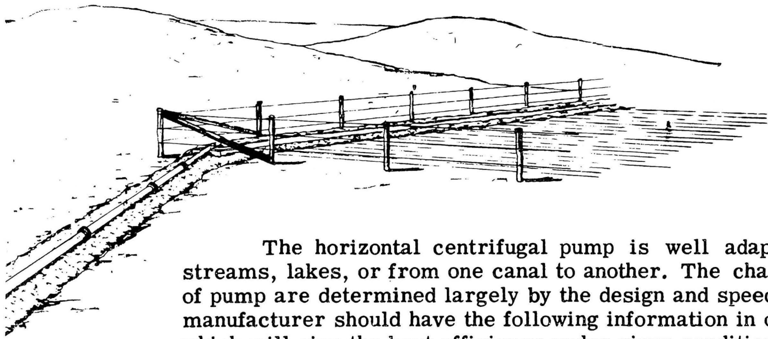


Fig. 2. Pumping from Open Water.



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.

FRICTION LOSS PER 100 FEET OF COMMON USED PIPE AND LOSS DUE TO FITTINGS

GALLONS PER MINUTE	DIAMETER OF PIPE				
	4-IN.	5-IN.	6-IN.	8-IN	10-IN.
	FRICTION HEAD IN FEET				
400	15.82	5.33	2.21	0.56	-----
450	19.75	6.65	2.74	0.64	0.21
500	24.08	8.12	3.26	0.81	0.28
750	-----	17.22	7.00	1.74	0.59
1,000	-----	-----	12.04	3.02	1.01
1,250	-----	-----	18.20	4.45	1.51
1,500	-----	-----	-----	6.27	2.09
2,000	-----	-----	-----	10.71	3.50
FRICTION LOSSES THRU PIPE FITTINGS IN TERMS OF EQUIVALENT LENGTHS OF PIPE					
GATE VALVE	3.44	4.57	5.72	8.10	10.70
MEDIUM SWEEP ELBOW	5.77	7.68	9.61	13.60	17.97
STND ELBOW	9.22	12.20	15.30	21.71	28.70

Courtesy of U. S. Farm Security Administration

Fig. 2 Continued.

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.

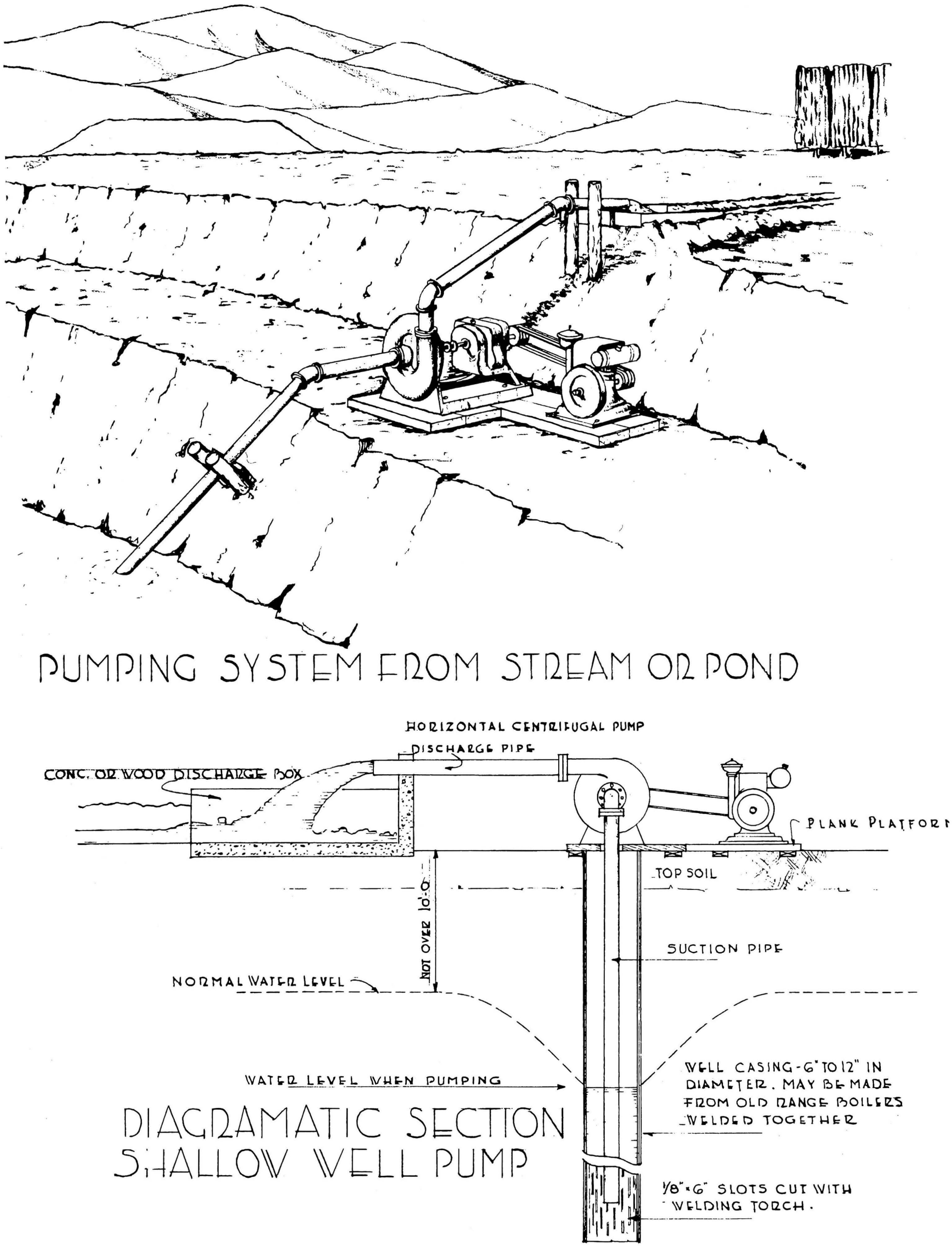
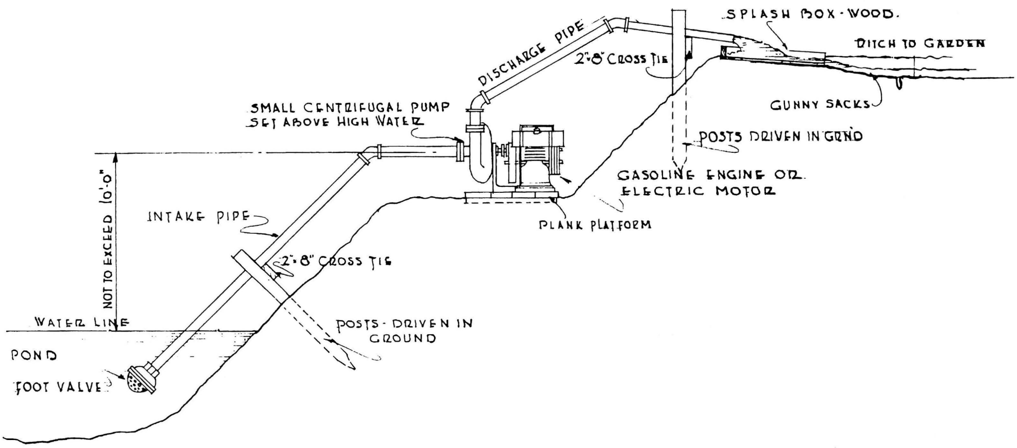


Fig. 3. Pumping from Open Water and Open Wells.



DIAGRAMATIC SECTION OF PUMP SYSTEM FROM STREAM OR POND

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.

Courtesy of U. S. Farm Security Administration

Fig. 3 Continued.

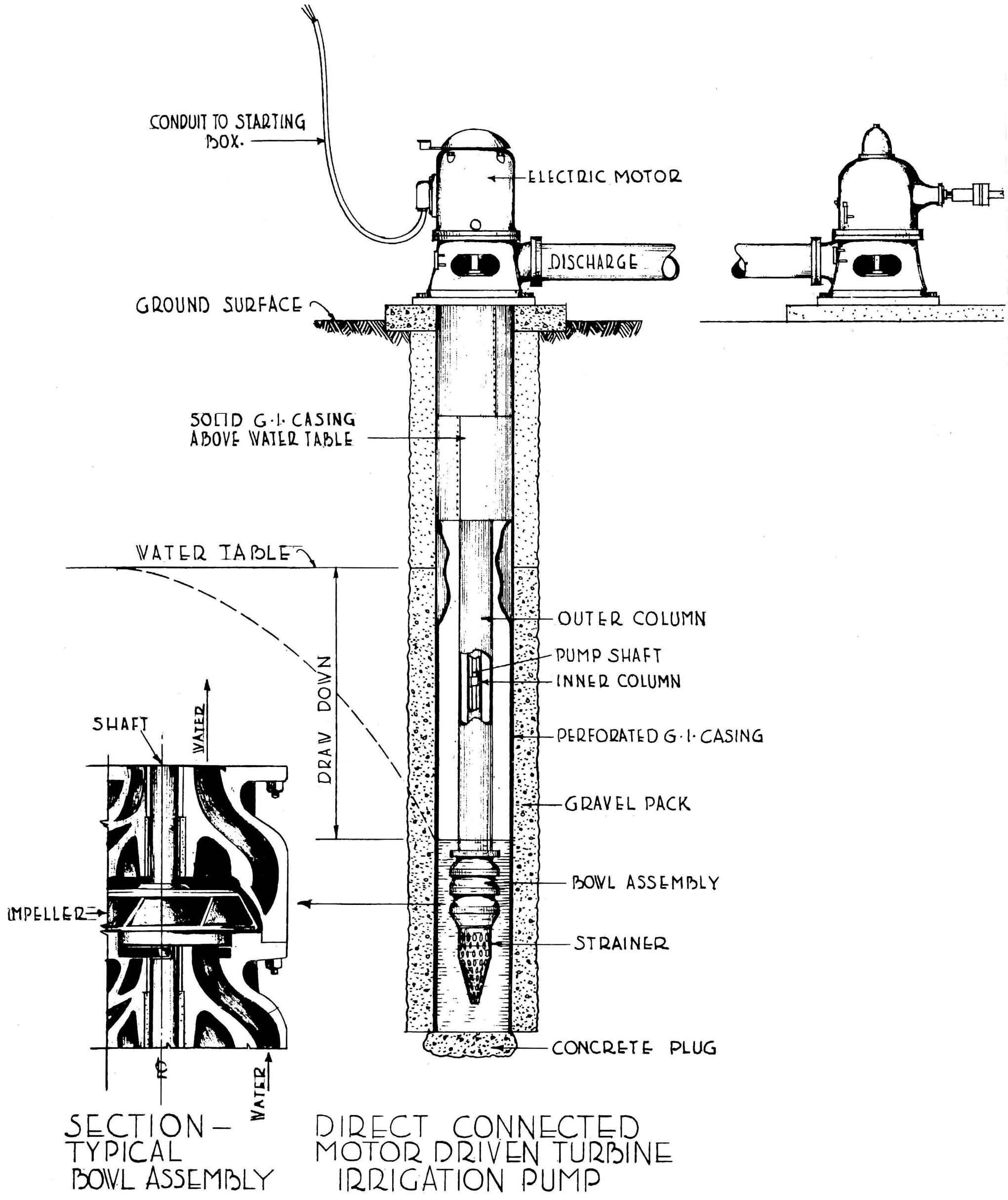
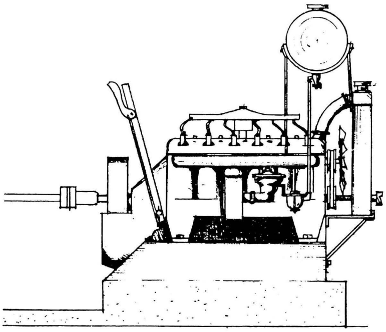
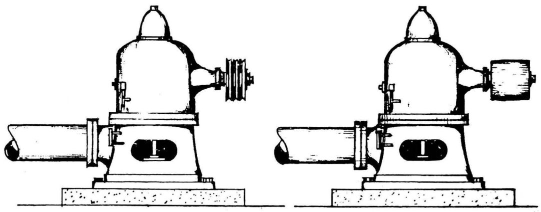


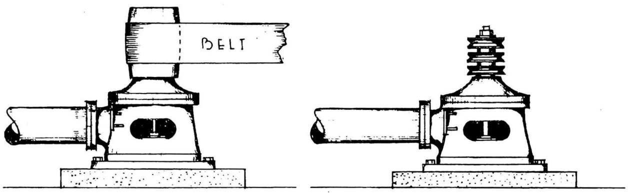
Fig. 4. Pumping from Wells by Turbine and Propeller Pumps.



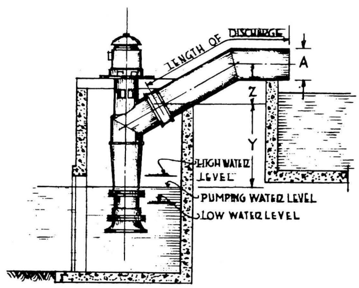
TURBINE TYPE IRRIGATION PUMP WITH GEAR HEAD CONNECTED TO A POWER UNIT WITH A SHAFT AND DOUBLE UNIVERSAL JOINT.



IRRIGATION PUMP GEAR HEAD WITH EITHER V-BELT OR FLAT-BELT DRIVE PULLEY.



TURBINE TYPE IRRIGATION PUMP WITH HEAVY DUTY BELTED HEAD FOR EITHER FLAT OR V-TYPE BELTS.



PROPELLER TYPE IRRIGATION PUMP

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.

Courtesy of U. S. Farm Security Administration

Fig. 4 Continued.

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

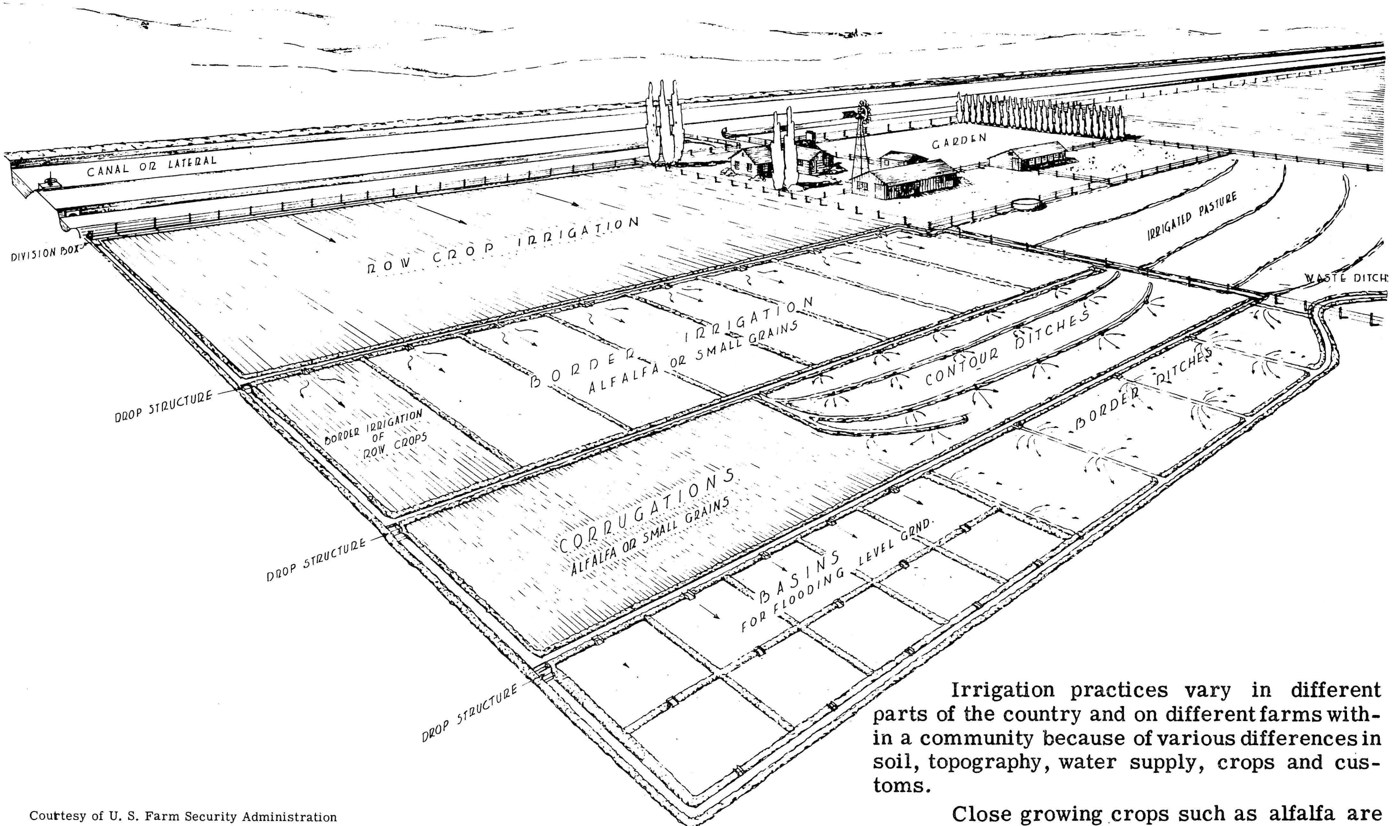
The least expensive method of conveying the water is by permanent or temporary canals or ditches (Figs. 5, 6, 12, 13, 14, and 15), but there is considerable loss of water and loss of the land occupied by the canals or ditches. They are economically constructed by ditchers such as that shown in Figs. 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 20-, 30-, and 40-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.



Courtesy of U. S. Farm Security Administration

Fig. 5. General Layout of an Irrigated Farm.

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.

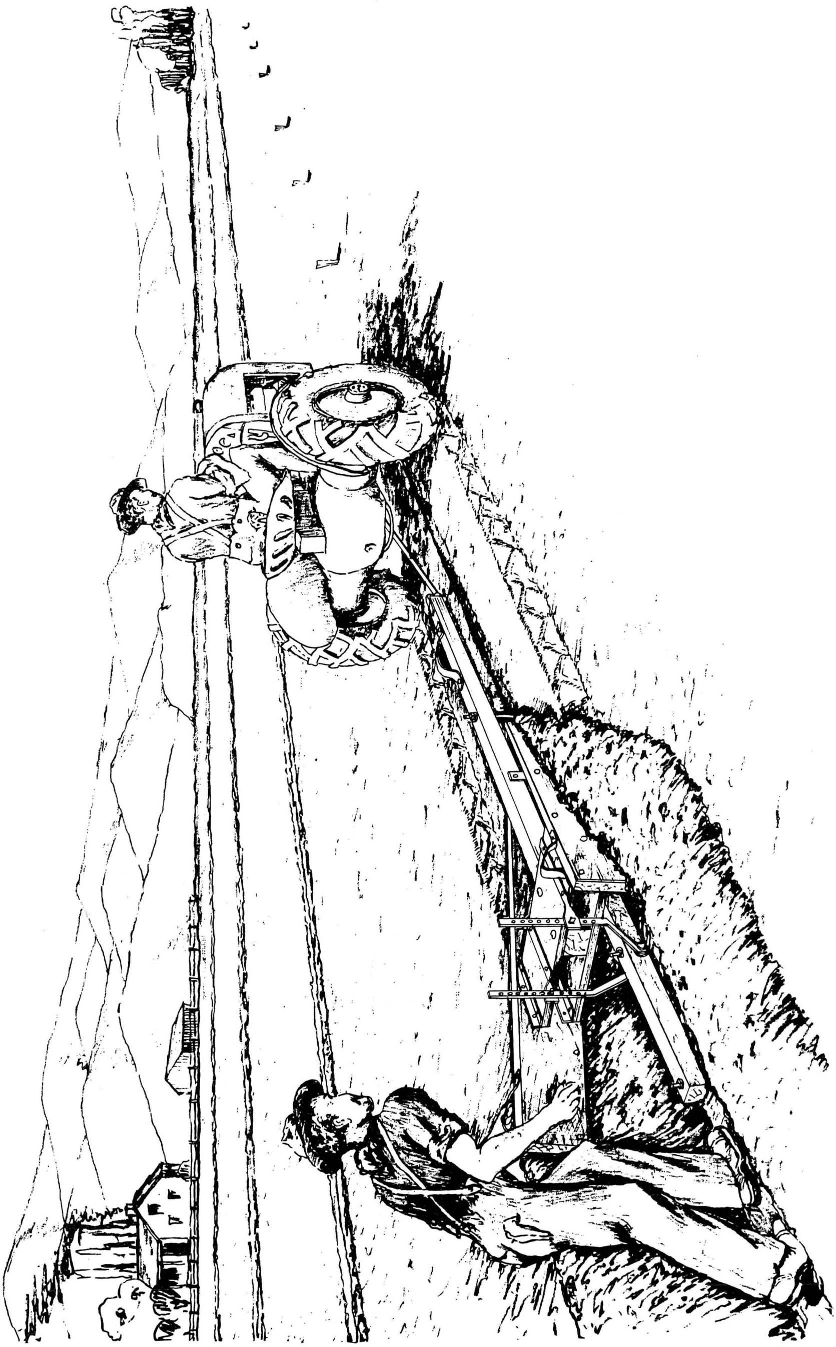
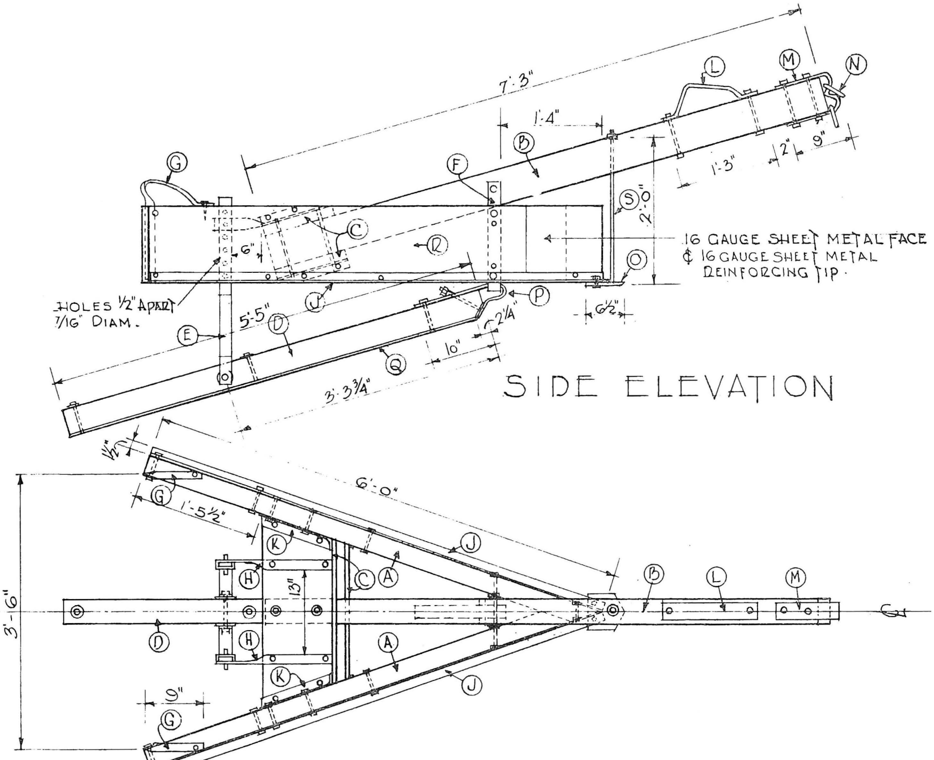


Fig. 6. Irrigation Ditcher.



PLAN

BILL OF MATERIAL FOR IRRIGATION DITCHER

WOOD

- (A) 2 - 3" × 12" × 6'-0" BRIDGE PLANK-(SIDES)
- (B) 1 - 4" × 6" × 8'-0" HICKORY OR OAK-(TONGUE)
- (C) 2 - 2" × 12" × 2'-6" PINE SPREADERS
- (D) 1 - 4" × 4" × 6'-0" HICKORY OR OAK-(SKID)

IRON

- (E) 2 - 1/2" × 1 1/2" × 3'-0" STRAP IRON (HEIGHT ADJUSTERS)
- (F) 1 - 1/2" × 2" × 3'-4" STRAP IRON (SKID SUPPORT)
- (G) 2 - 1/2" × 1 1/2" × 2'-0" STRAP IRON (HANDLES)
- (H) 2 - 1/2" × 1 1/2" × 1'-9" STRAP IRON (HEIGHT ADJUSTER CHECKS)
- (J) 2 - 1 1/2" × 1 1/2" × 6'-0" ANGLE IRON (SIDE SHOES)
- (K) 4 - 1 1/2" × 1 1/2" × 1'-0" ANGLE IRON (SPREADER SUPPORTS)
- (L) 1 - 1/2" × 2 1/2" × 1'-8" STRAP IRON
- (M) 1 - 1/2" × 2 1/2" × 2'-6" STRAP IRON (CLEVIS)
- (N) 2 - 3/8" × 4" DIAM. RINGS (CLEVIS)
- (O) 1 - 3/8" × 5" × 6 1/2" FLAT PLATE
- (P) 1 - 1/2" × 2" × 1'-8" STRAP IRON (SKID CLEVIS)
- (Q) 1 - 3/8" × 4" × 5'-6" STRAP IRON (SKID SHOE)
- (R) 2 - 12" × 6'-0" #16 GAUGE GALV. IRON (SIDE PROTECTION)
  1 - 12" × 2'-0" #16 GAUGE REINFORCING TIP.

BOLTS

- (S) 1 - 3/4" × 24"
- 2 - 5/16" × 1 1/2" "U" PIECE ELEVATOR (E)
- 2 - 5/16" × 7" TONGUE CLEVIS (M) TO (B)
- 2 - 3/8" × 7" TONGUE SKID (L) TO (B)
- 2 - 3/8" × 9 3/4" - TONGUE, TO CROSSBOARDS (C)
- 4 - 5/16" × 3" ELEVATOR GUIDES (E) TO CROSSBOARDS (C)
- 8 - 1/4" × 2 1/4" - ANGLE IRON (K) TO CROSSBOARDS (C)
- 10 - 1/4" × 3 3/4" - 8 FROM ANGLE IRON (K) TO BEAM (A)
  2 FOR TOP BOLTS IN HANDLES
- 4 - 3/8" × 4 1/2" - BOTTOM SKID (Q) TO BEAM (D)
- 6 - 3/8" × 3 1/2" - ANGLE IRON (J) TO BEAM (A)
- 2 - 3/8" × 1" - TRIANGULAR PLATE (O) TO ANGLE IRON (J)
- 4 - 3/8" × 4" - FRONT "U" IRON (F) TO BEAM (A)
- 1 - 3/8" × 6" - FRONT "U" IRON (F) TO TONGUE (B)
- 2 - 3/8" × 12" - COLLAR-TIE FOR BEAMS (A)
- 1 - 3/8" × 5" - "U" PIECE ELEVATOR (E) TO SKID (D)
- 2 - 3/8" × 2" - LAG SCREWS FOR HANDLES.

WASHERS

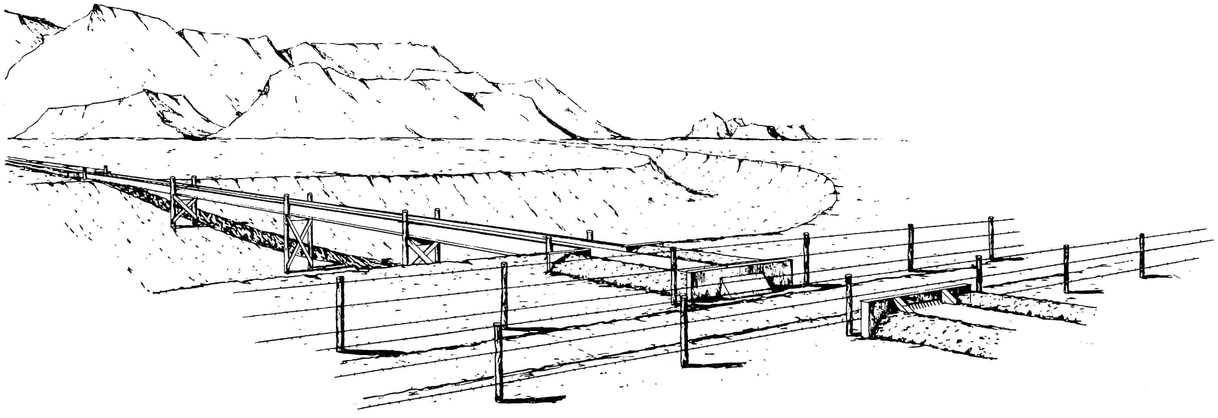
- 16 FOR 1/4" BOLTS
- 4 FOR 5/16" BOLTS
- 18 FOR 3/8" BOLTS

NAILS

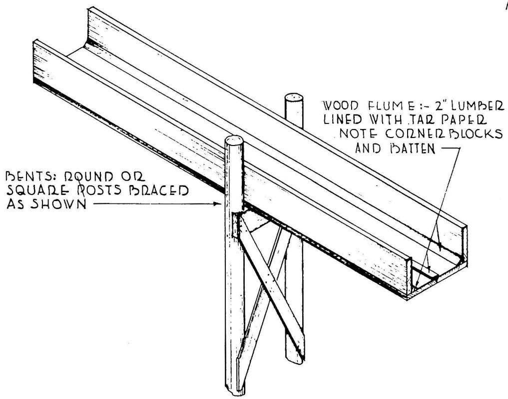
APPROXIMATELY 100 - 8 PENNY WIRE
6 - LARGE SPIKES.

Courtesy of U. S. Farm Security Administration

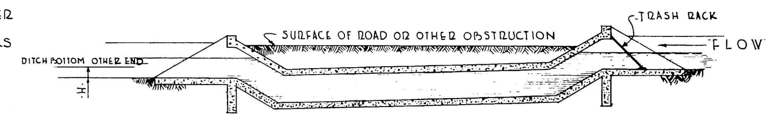
Fig. 6 Continued.



TRANSPORTING WATER UNDER LANE AND ACROSS GULLY BY USE OF INVERTED SIPHON AND FLUME



FLUME SECTION



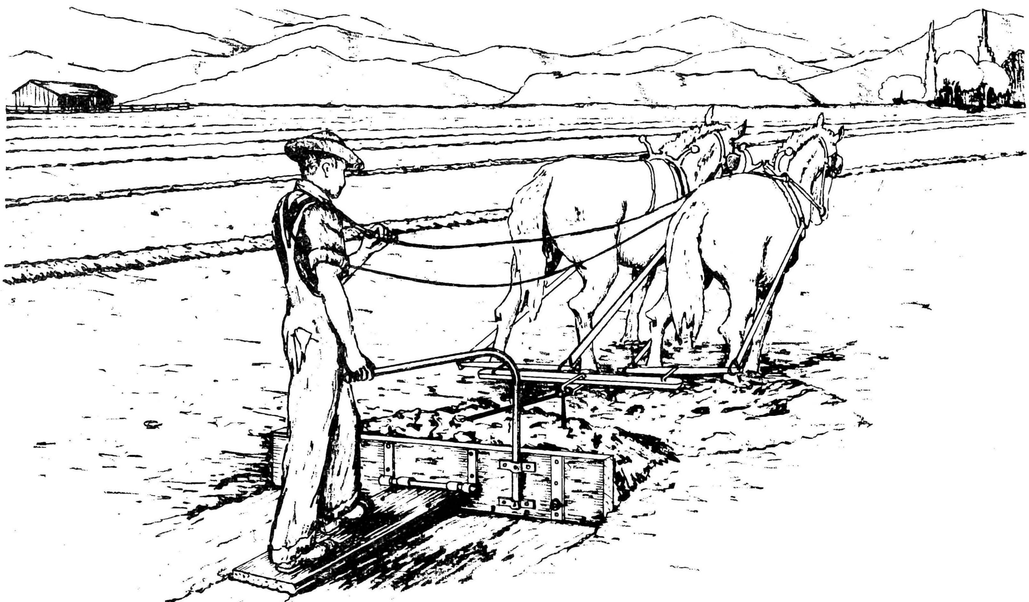
DIAGRAMATIC SECTION OF INVERTED SIPHON

CAPACITY OF SIPHON IS DEPENDENT ON DIAMETER, LENGTH AND KIND OF PIPE, AND DIFFERENCE IN ELEVATION (H)

Courtesy of U. S. Farm Security Administration

Fig. 7. Wooden Flume.

Fig. 8. Rapid Coupling for Portable Pipe. Courtesy of Aluminum Company of America.



BILL OF MATERIAL "BUCK SCRAPER"

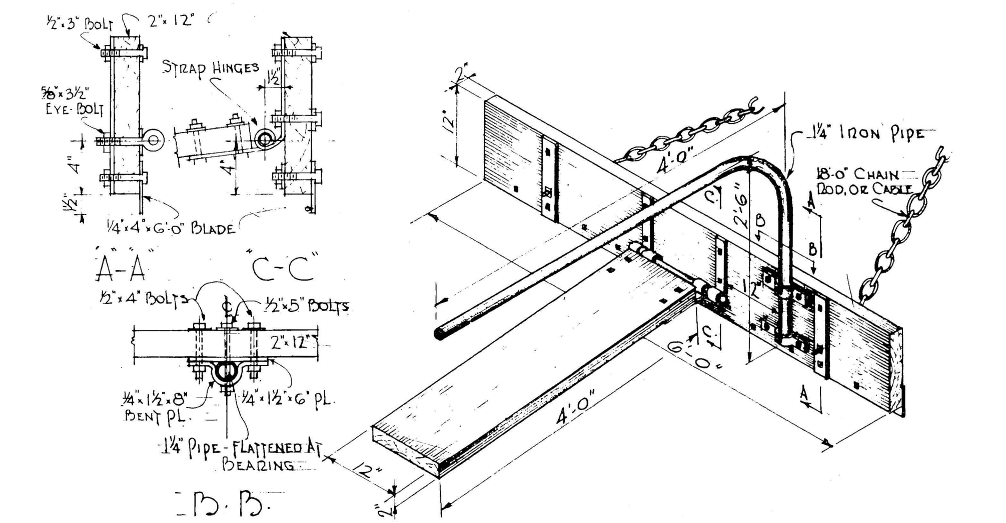
1 - 2"×12"×6'-0" - BUCK BOARD
1 - 2"×12"×4'-0" - TRAILER BOARD
1 - 1¼"×6'-6" - IRON PIPE HANDLE
1 - ¼"×4"×6'-0" - STRAP IRON CUTTING EDGE
4 - ¼"×1½"×12" - STRAP IRON HINGES
2 - ¼"×2"×12" - STRAP IRON
2 - ¼"×1½"×6" - STRAP IRON --- PIPE CLAMP
2 - ¼"×1½"×8" - BENT STRAP IRON " "
1 - ⅝"×18" - BOLT FOR HINGE
2 - ⅝"×3½" - EYE-BOLTS
2 - ½"×5" - CARRIAGE BOLTS
4 - ½"×4" - " "
22 - ½"×3" " "
2 - ⅝" WASHERS
28 - ½" "
18'-0" CHAIN-ROD-OR CABLE HITCH.

BILL OF MATERIAL "CUTTING FLOAT"

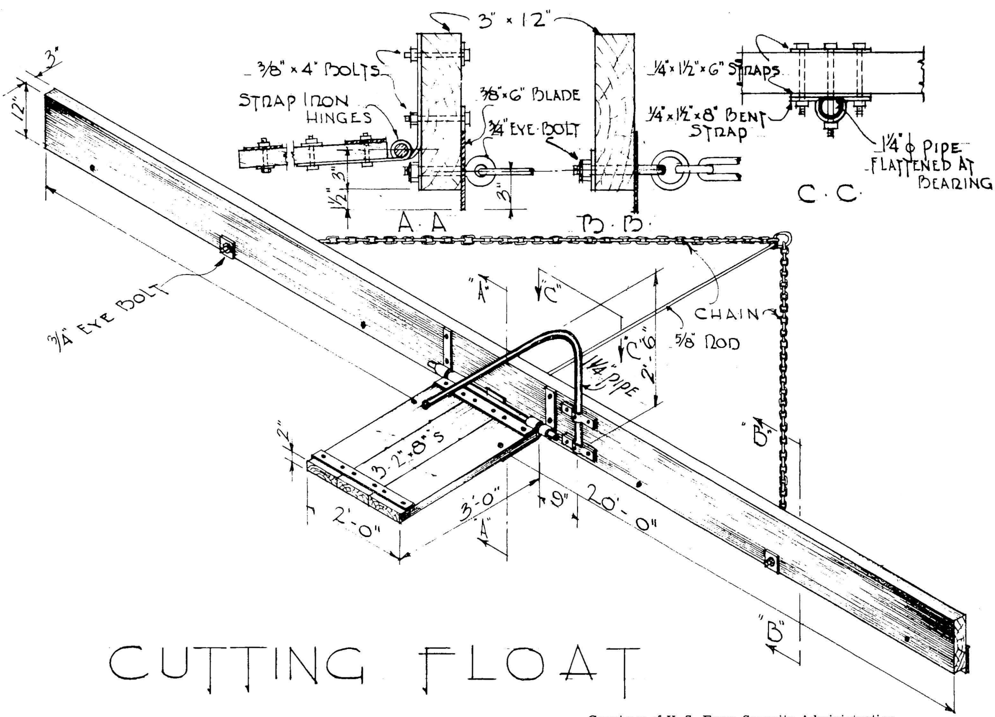
1 - 3"×12"×20'-0" BUCK BOARD
3 - 2"×8"×3'-0" FOR TRAILER BOARD
1 - 1¼"×6'-0" - IRON PIPE HANDLE
1 - ⅜"×6"×20'-0" STRAP IRON CUTTING EDGE
4 - ¼"×1½"×12" - STRAP IRON HINGES
2 - ¼"×3"×2'-0" - STRAP IRON CLEATS
3 - ¼"×3"×3" - FLAT WASHERS
4 - ¼"×1½"×6" - STRAP IRON - PIPE CLAMP
2 - ¼"×1½"×8" " " " "
1 - ¾"×2'-6" BOLT FOR HINGE
3 - ¾"×5" - EYE BOLTS
2 - ½"×6" - CARRIAGE BOLTS.
4 - ½"×5" " "
14 - ½"×3" " "
8 - ½"×4" " "
22 - ½" WASHERS
1 - ⅝" φ ×6'-0" ROD FOR HITCH
2 - 9'-0" CHAINS, CABLE, OR RODS FOR HITCH
1 - 4" RING FOR HITCH.

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.



BUCK SCRAPER FOR WET AND DRY LEVELING



CUTTING FLOAT

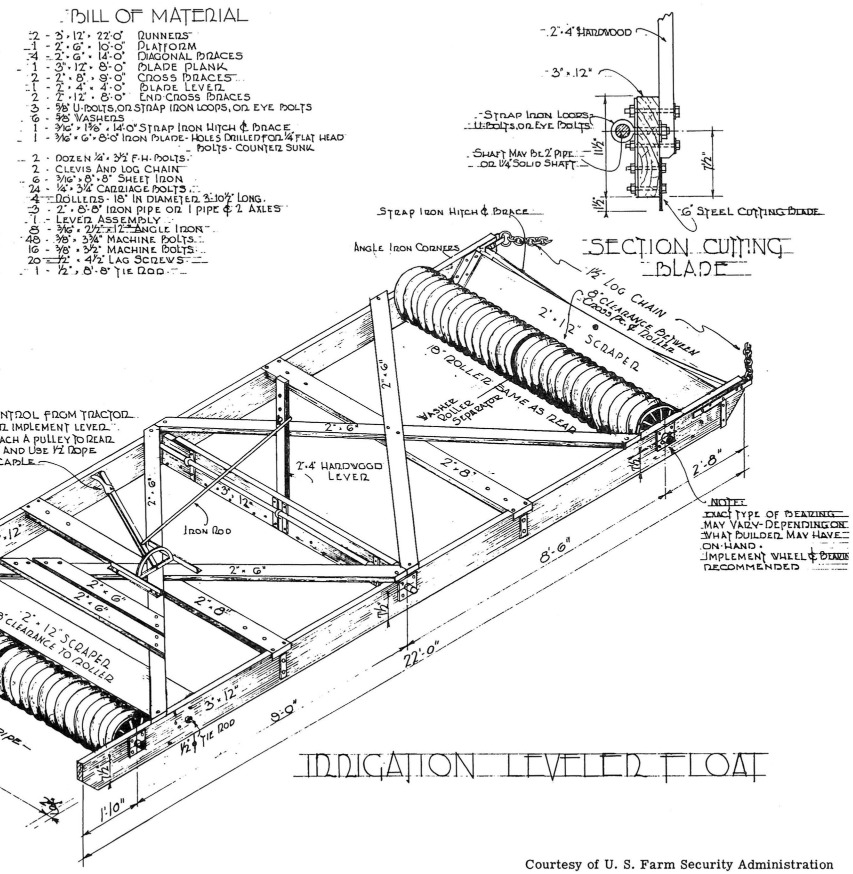
Courtesy of U. S. Farm Security Administration

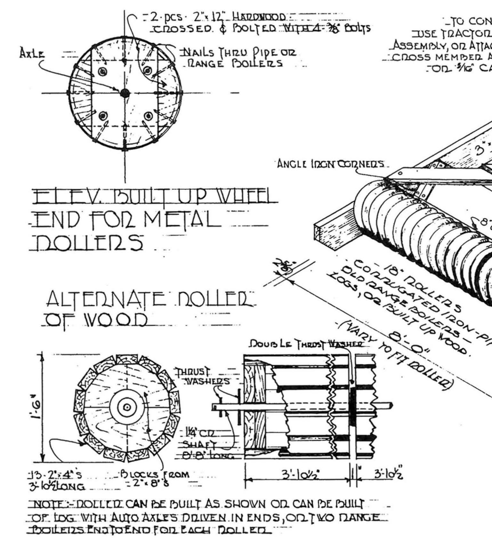
Fig. 9 Continued.

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.





Courtesy of U. S. Farm Security Administration

Fig. 10. Float for Land Leveling.

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 46 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 best. Often the irrigation layout can be planned to aid drainage and early Spring plowing (Reference 35a).

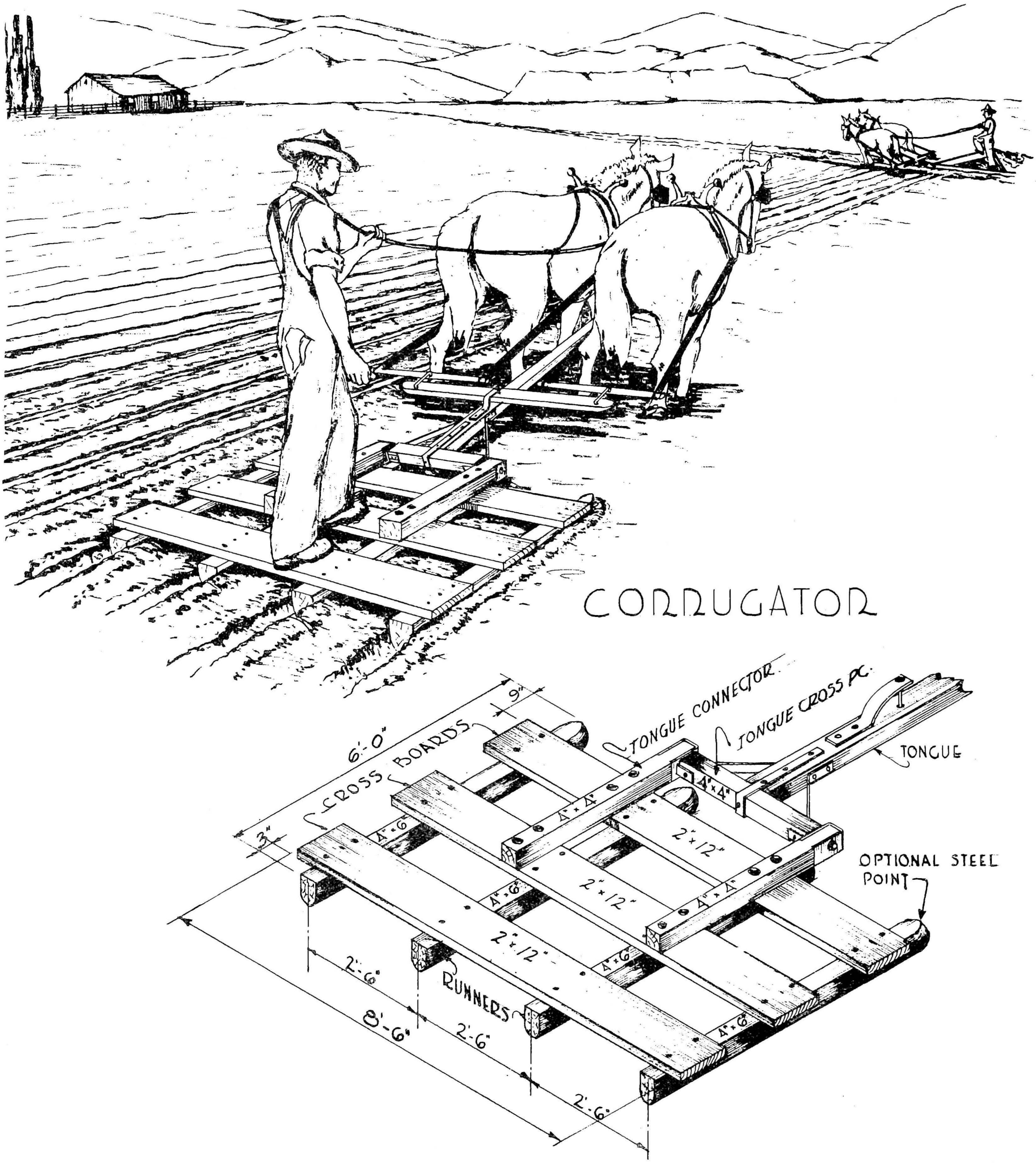
SURFACE IRRIGATION

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.

Not always in Missouri will it pay to *level* (that is, to smooth—not to make 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, or of special tillage machinary which simply cuts through the soil, will avoid disturbing the leveled surface.

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 flumes, outline the areas to be left unirrigated, assist in any necessary leveling, and generally prevent difficulties and save money. Such maps

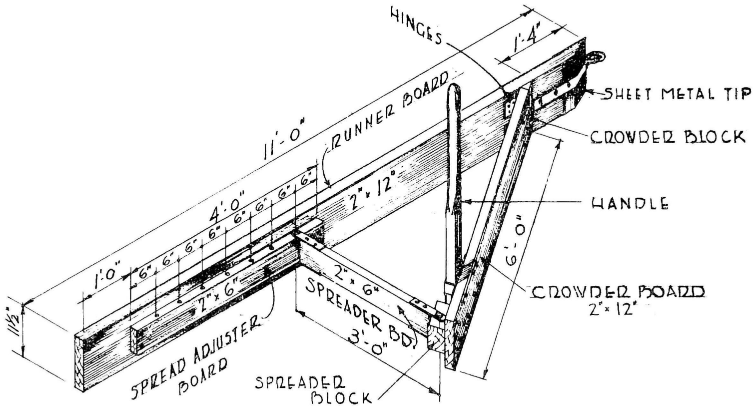


The corrugator is a device used to make small furrows or corrugations for conducting irrigation water over the ground surface. Corrugations are particularly adapted to watering grain or hay crops on irregular fields or for new fields which have not been thoroughly leveled and floated.

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.

ADJUSTABLE CROWDER



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

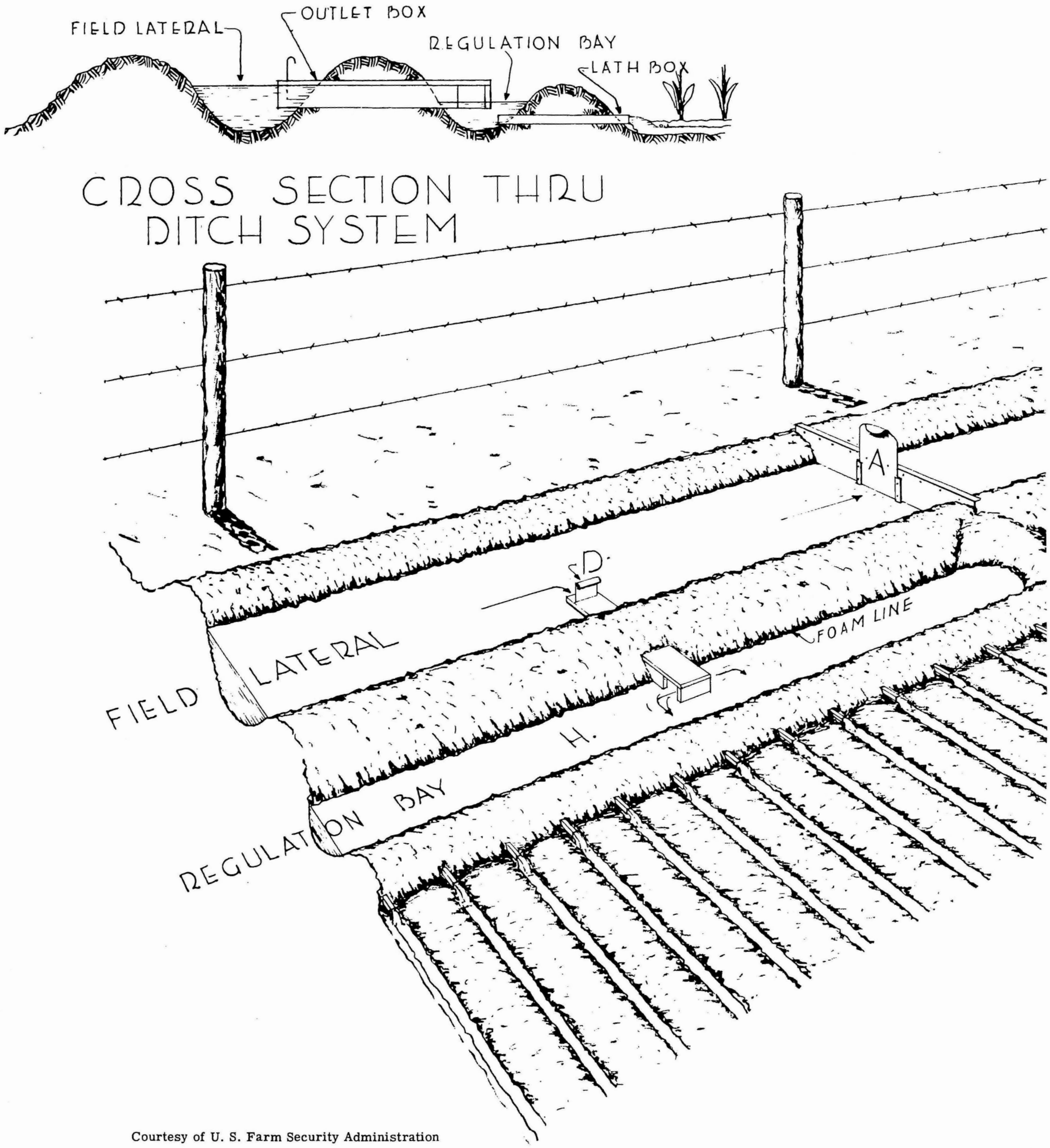
1 PC. 2"×12"×11'-0" RUNNER BOARD
1 PC. 2"×12"×6'-0" CROWDER BOARD
1 PC. 2"×6"×3'-0" SPREADER BOARD
1 PC. 2"×6"×4'-0" SPREAD ADJUSTER BOARD
1 PC. 1½"×2½"×4'-6" HARDWOOD HANDLE
1 PC. 4"×6"×6" - SPREADER BLOCK
1 PC. 3/8"×2"×36" STRAP IRON WITH 3/4" RND-2½" DIA. HITCH RING.
2 PCS. 3/8"×2"×10" HANDLE SUPPORTS.
4 PCS. 3/8"×1¾"×8" SPREADER BOARD ENDS.
1 PC. 12"×12" HEAVY SHEET METAL CUTTING POINT.
3- 3/8"×3" BOLTS - HITCH RING TO RUNNER BD.
3- 1/4"×4" BOLTS - CROWDER BLK. TO RUNNER BD.
16- 1/4"×2½" BUTTON HEAD BOLTS FOR HINGES
8- 1/4"×2½" BOLTS FOR HANDLE SUPPORTS.
4- 3/8"×7" " " SPREADER BLOCK
2- 1/2"×7" " " " BOARD BEARINGS
4- 3/8"×7" " " " " TIPS.
6- 1/2"×5" " " SPREADER ADJ. BD TO RUNNER.
2-PCS. 3" SURFACE HINGES

CORRUGATOR

4 PCS.- 4"×6"×6'-0" FOR RUNNERS
3 PCS.- 2"×12"×8'-6" FOR CROSS BOARDS
2 PCS. 4"×4"×4'-0" FOR TONGUE CONNECTOR
1 PC. 4"×4"×2'-10" FOR TONGUE CROSS PC.
1 PC. OLD WAGON TONGUE
1 PC. 1/4"×2½"×12" STRAP IRON CLEVIS.
1 PC. 1/4"×1½"×3'-0" " " TONGUE TO CROSS PC.
2 PCS. 1/4"×2"×3'-0" " " TONGUE BRACES
2 PCS. 1/4"×4"×1'-4" " " TONGUE CONNECTOR ENDS
1- 3/4"×8" BOLT - DOUBLE TREE TO CLEVIS.
2- 3/8"×6" " - CLEVIS TO TONGUE
7- 1/2"×6" " - TONGUE TO CROSS TIE.
1- 1/2"×8" LAG SCREW- CROSS TIE TO TONGUE
2- 5/8"×12" " " CONNECTOR TO CROSS TIE AXLE
8- 3/8"×8" BOLTS WITH WASHERS- TONGUE CONNECTORS TO CROSS BOARDS.
24- 5/16"×8" CGE. BOLTS-HDS. IN RUNNERS- CROSS BOARDS TO RUNNERS.

Courtesy of U. S. Farm Security Administration

Fig. 11 Continued.



Courtesy of U. S. Farm Security Administration

Fig. 12. Furrow Irrigation, with Lath Boxes.

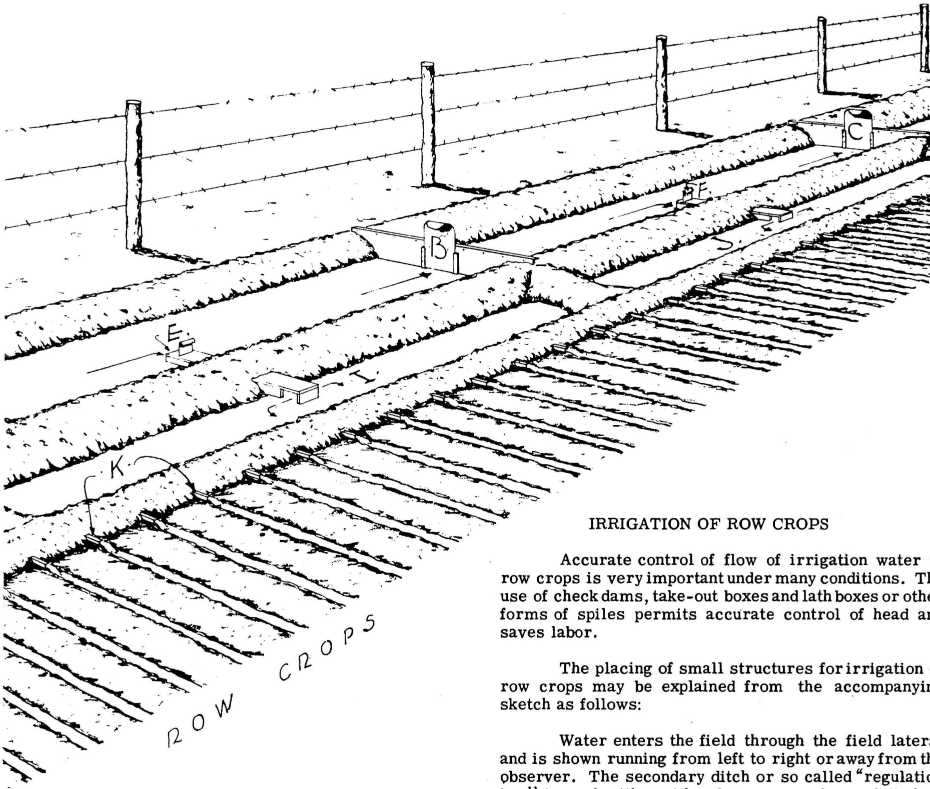


Fig. 12 Continued.

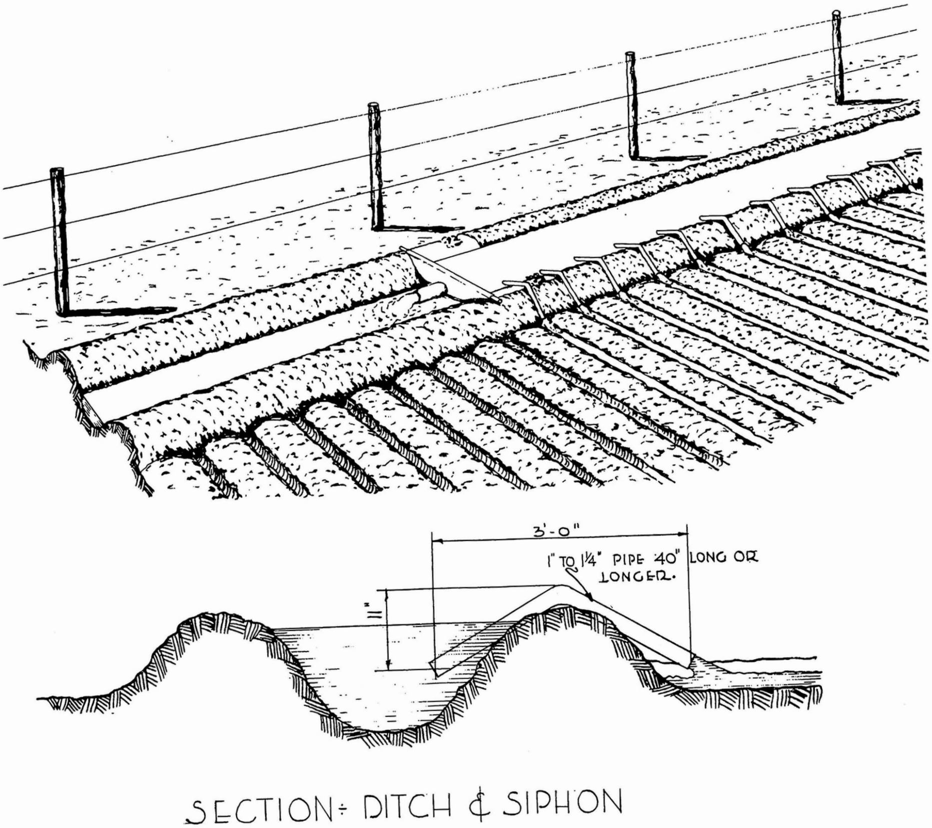
IRRIGATION OF ROW CROPS

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 "D" 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.

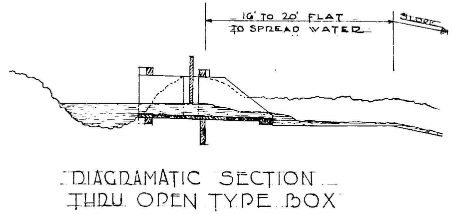
The siphon action is started as follows:

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.

Courtesy of U. S. Farm Security Administration

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.



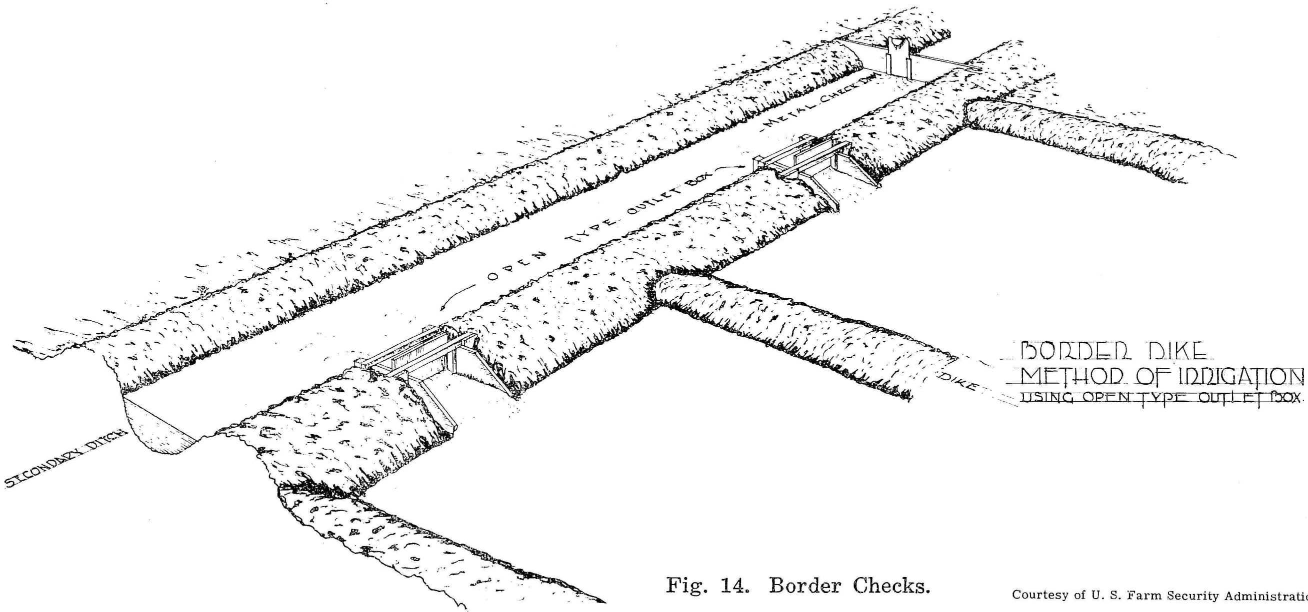


Fig. 14. Border Checks.

Courtesy of U. S. Farm Security Administration 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; and on pages 12 and 14 of Reference 14i.

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 or gated surface pipes (not shown on the figures) 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. It is common practice to double the flow of water in the furrow until it reaches the lower end, then to reduce to the following normal flow. From 1½ to 10 gallons per minute is ordinarily used and the larger flows will erode usual soils badly on slopes of 24 inches per 100 feet or more. Furrows must generally run squarely down the slope which should preferably be between 2 and 8 inches per 100 feet.

Corrugations, Fig. 11, aid in distributing water on uneven ground but interfere to some extent with harvesting a crop.

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 $1\frac{1}{2}$ to $3\frac{1}{2}$ 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.

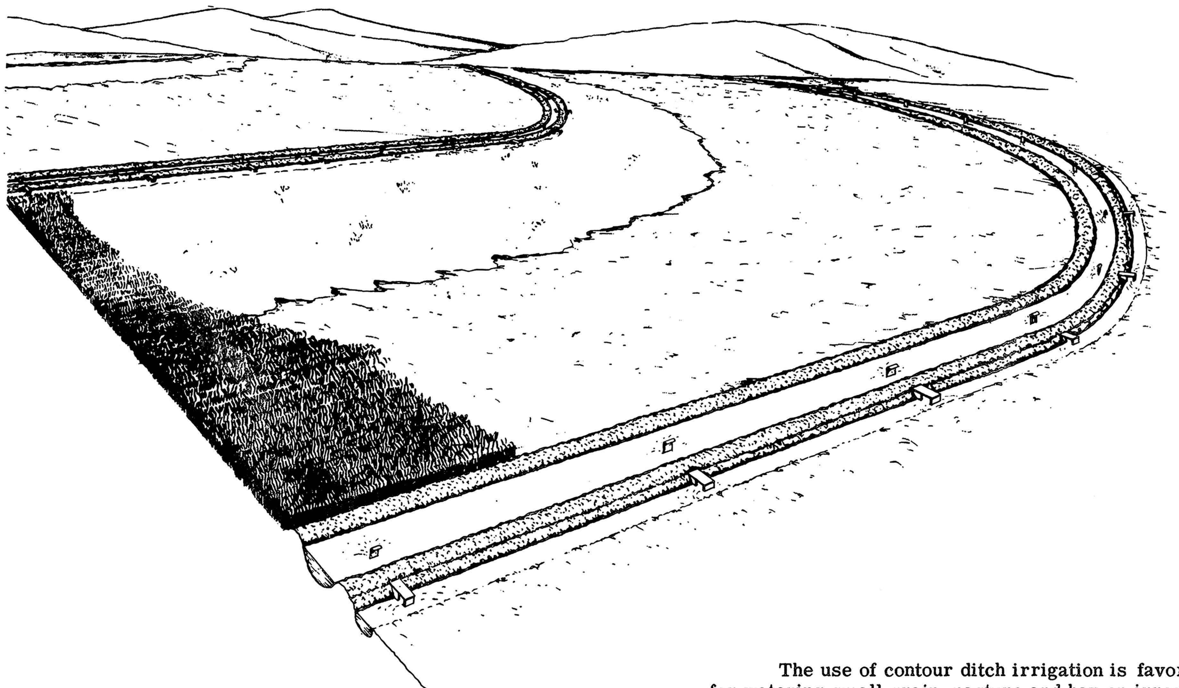
Wild Flooding. Here the water is distributed from ditches along contours, at right angles to contours, along ridges, or along high ground. Although inefficient, it is widely used for other than row crops. Little leveling is necessary.

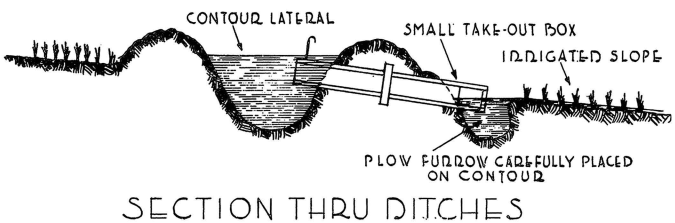
Because of the lack of guide furrows or embankments for the water used in wild flooding, the supply ditches are spaced from 200 feet apart on slopes of from 5 to 8 feet per 100 feet to 400 feet or more apart on heavy soils with slopes of 1 foot per 100 feet or less.

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.

Courtesy of U. S. Farm Security Administration

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. Where furrows run down the slope, only trickles of water are used in short furrows. If the deep furrows follow the contour across the slope, as in some orchard irrigation, the usual 10 gallons per minute may be used in each furrow. Terraces are sometimes used for the distribution of irrigation water.

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.

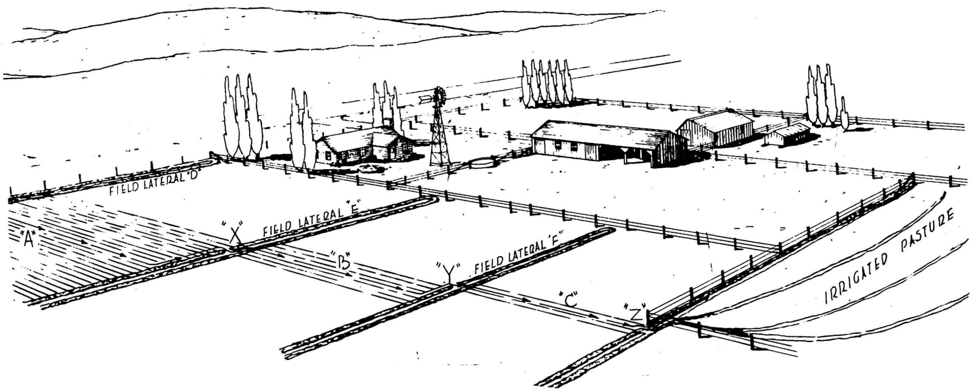
Of course, porous hose and sprinklers can be used on both flat and steep slopes.

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 roadside 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 irrigated 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 land leveling and the field ditches for irrigation may be arranged 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 (Reference 35a).



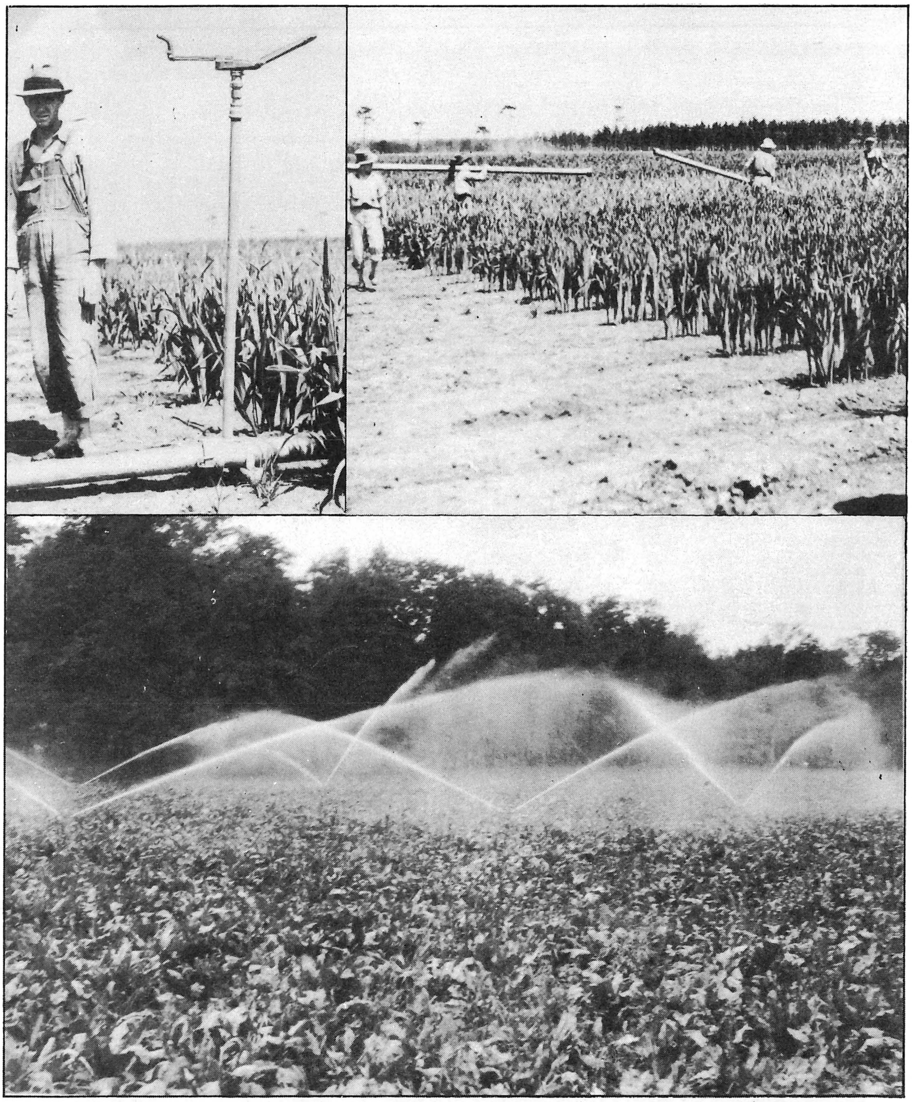
Courtesy of U. S. Farm Security Administration

Fig. 16. Disposal of Excess Water.

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 (References 44, 45, and 45a).

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 45a 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.

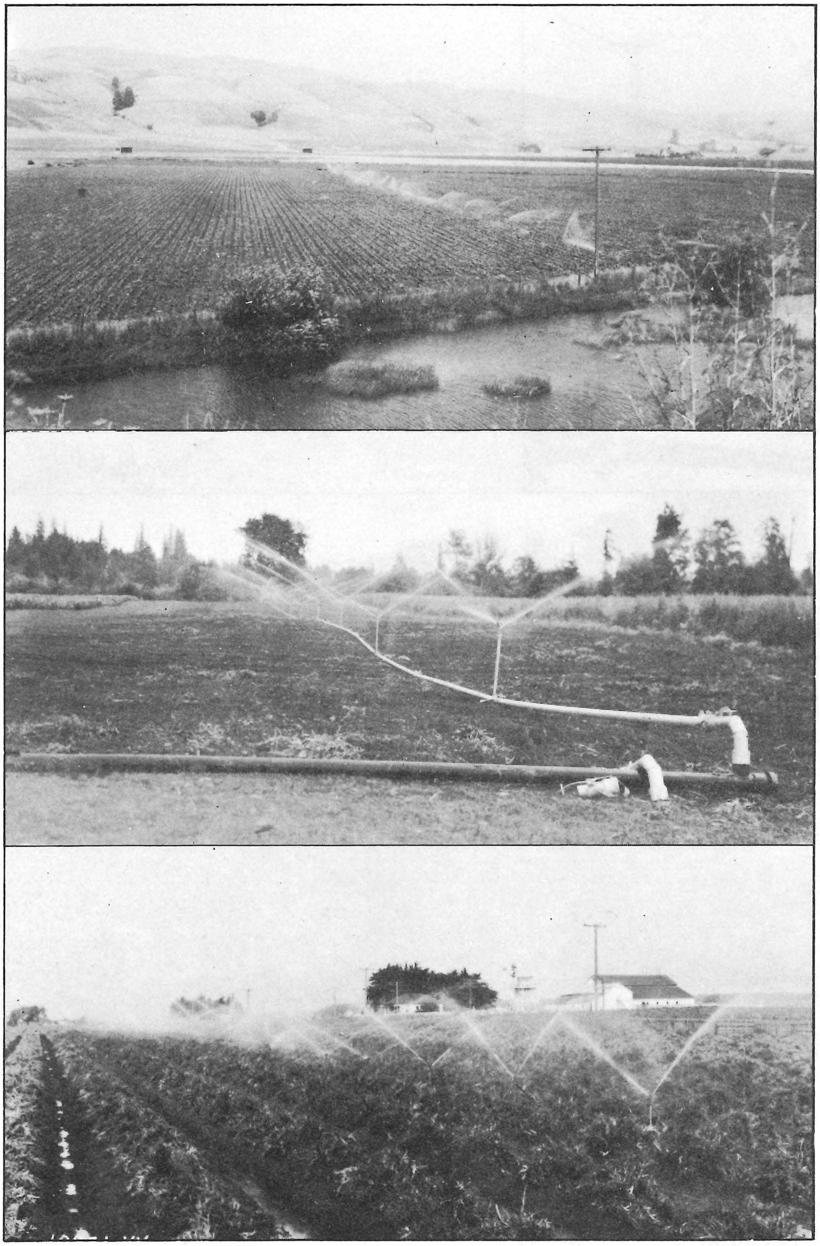


Courtesy of Skinner Irrigation Company

Fig. 17. Portable Pipe and Rotary Sprinklers.

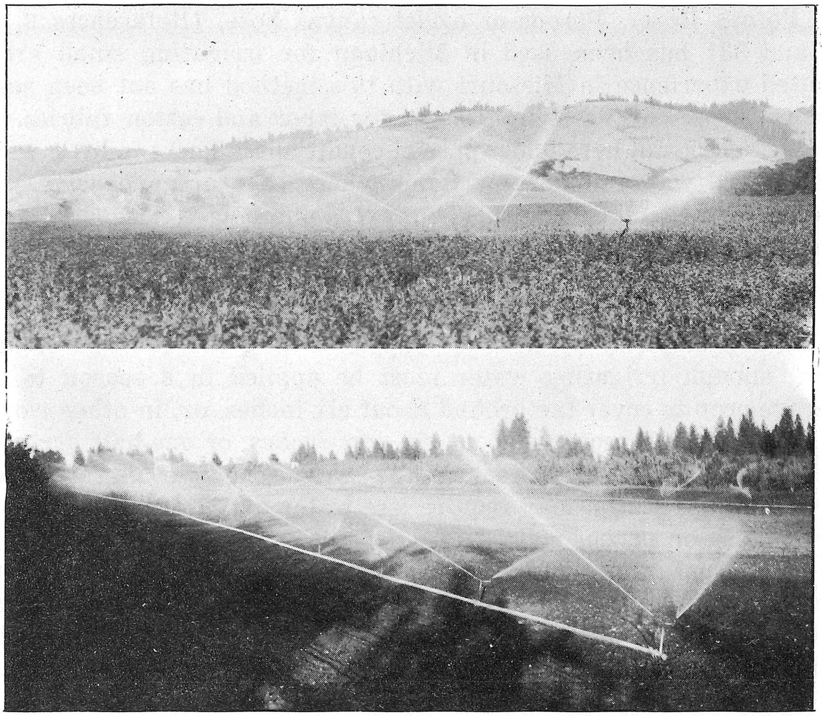
Figure 21 shows a typical simple sprinkling system in which the 3-inch portable laterals are moved to successive outlets on the permanent underground main. Many alternate layouts can be used, and each irrigation development requires its individual solution.

Few irrigators use sprinklers for corn or such tall crops because of handling difficulties, and because the rows are well adapted to furrow irrigation.



Courtesy of California Culvert Company

Fig. 18. Sprinkler Irrigation.



Courtesy of California Culvert Company

Fig. 19. Sprinkler Irrigation for Alfalfa and Clover.

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. 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, both water and land are saved, and deep percolation is minimized for thin or porous soils. 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 with pumping units of from $75 to $125 per acre are common throughout the country. Agents for the manufactures and distributors will gladly furnish information, designs, and bids, on suitable systems for a particular farm. It is wise to have an irrigation engineer approve the proposal.

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 one to two inches of water at one time, but the amount required may vary from one-half 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.

There are many variables governing the question of "when and how much" irrigation, and judgment must be developed through local experiment and experience. When a crop wilts, irreparable damage usually has occurred. Only in special cases should more than 10 or 12 days elapse between applications of water, either rain or irrigation. On the other hand, too much water, as could occur with a heavy rain following an irrigation, can leach the plant nutrients from the soil and cause other trouble. It is safest to apply water according to the moisture content of the soil—perhaps when it is below 15%—as determined by borings and samplings with a soil auger, soil tube, or otherwise (Reference 14k and page 55) and according to the prospect for predicted effective rain. Weather forecasting continues to improve. Uniformity and depth of irrigation throughout the field must likewise be tested by sampling.

A good "rule of thumb" is to apply water at the rate of one inch, or a little more, per week—rainfall and irrigation included—then to change from this as experience and special conditions indicate. It may take a week or more to irrigate the entire field, which requires careful planning ahead. Usually less than the foregoing rate of applying water will be necessary in the early life, or during the maturity, of the crop. More will be required during periods of maximum growth, high temperature, high wind, low humidity, and prolonged dry weather.

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 at the field.

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. Conveyence losses are excluded.

With furrows, an irrigator can ordinarily handle about one cubic foot of water per second at the field, and will apply one inch in depth of water to one acre in one hour. 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. 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 100 acres by the furrow, row, corrugation, or sprinkling method. An irrigating head, at the field, of one cubic foot per second will be used (perhaps a little more at the pump or source, to allow for losses). This will apply one and one-half inches of water to 65 acres in seven 14-hour days. Some authorities recommend two inches of water every seven days in extreme droughts, and this could be accomplished by 19-hour pumping. Because of seepage in the ditches, evaporation, deep percolation, and waste perhaps only one-half to three-quarters of this water reaches the plants.

However, crops in Missouri generally require only some six inches of irrigation water per season, and 65 acres will be irrigated over some 28 days of 14-hour pumping 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, more acreage, say 100 acres, may be irrigated in 43 days of 14-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 during the balance of the summer when rainfall was adequate.

It thus becomes apparent that under the conditions stated above, and if an irrigating head of one cubic foot per second at the field is suitable for the project, maximum economy of cost and labor will result on a diversified project of some 100 acres. Long pumping hours will be necessary only occasionally.

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 200 acres will be a desirable size of project.

Another way of looking at this would be to assume somewhat less depth of water used and somewhat less diversification. Here again one cubic foot per second should irrigate 100 acres and two cubic feet per second should irrigate 200 acres, always bearing in mind that these flows of water are at the field and do not include losses between the source and the field.

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.

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.

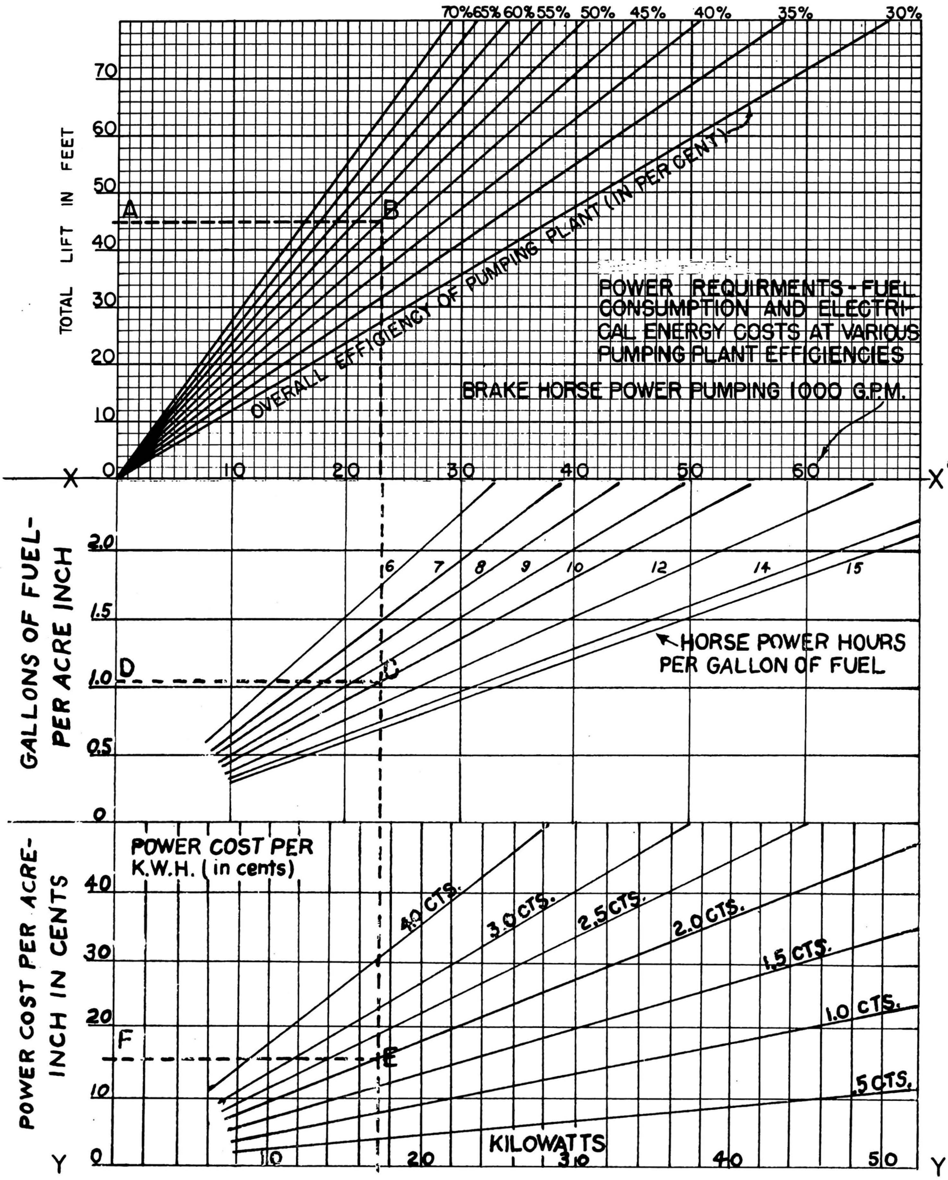
A modern electric motor and a 3- to 4-inch centrifugal pump for furnishing one cubic foot per second (450 gallons per minute) of water against usual pumping lifts (including the vertical lift, drawdown, and all friction losses) will cost several hundred dollars, excluding wiring and installation. A gasoline 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. Where a tractor is available, pumps can be purchased that operate from the power take-off.

First cost, maintenance, and attendance are a minimum for the newer grease-lubricated, ball-bearing, built-in-electric-motor-type pumping unit; and it is apt to be the most reliable.

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 1953 costs of irrigation to those not



Courtesy of U. S. Farm Security Administration

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:

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

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, taxes, and insurance of 7 to 10 percent annually of the original cost, or from $3.50 to $10 per acre per year. This permits the higher type of crop culture and yields possible with an assured water supply, and in addition may be considered in the nature of an "insurance premium" for protection against droughts, against decreased yields where rainfall is poorly distributed, and against interruptions in the permanent farm and livestock program caused by uncertain yields.

Each year that irrigation is used considerably, and this will be most years for most crops, the total annual cost for each acre, including the annual costs of the preceding paragraph, may be from $15 to $20. The average cost per acre over many years will be considerably less since wet years will occur, but the larger yields will be secured every year.

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

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 (from Reference 44) 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 in a dry year, and not including a well or other water source), 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.

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.

COMPARISON OF TOTAL ANNUAL COSTS PER ACRE BY SPRINKLER AND SURFACE METHODS

	SPRINKLING	SURFACE IRRIGATION
Interest, depreciation, taxes, and insurance	$10	$4
Labor applying water	4	10
Power	3	1
Maintenance	1	3
Totals	18	18

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.

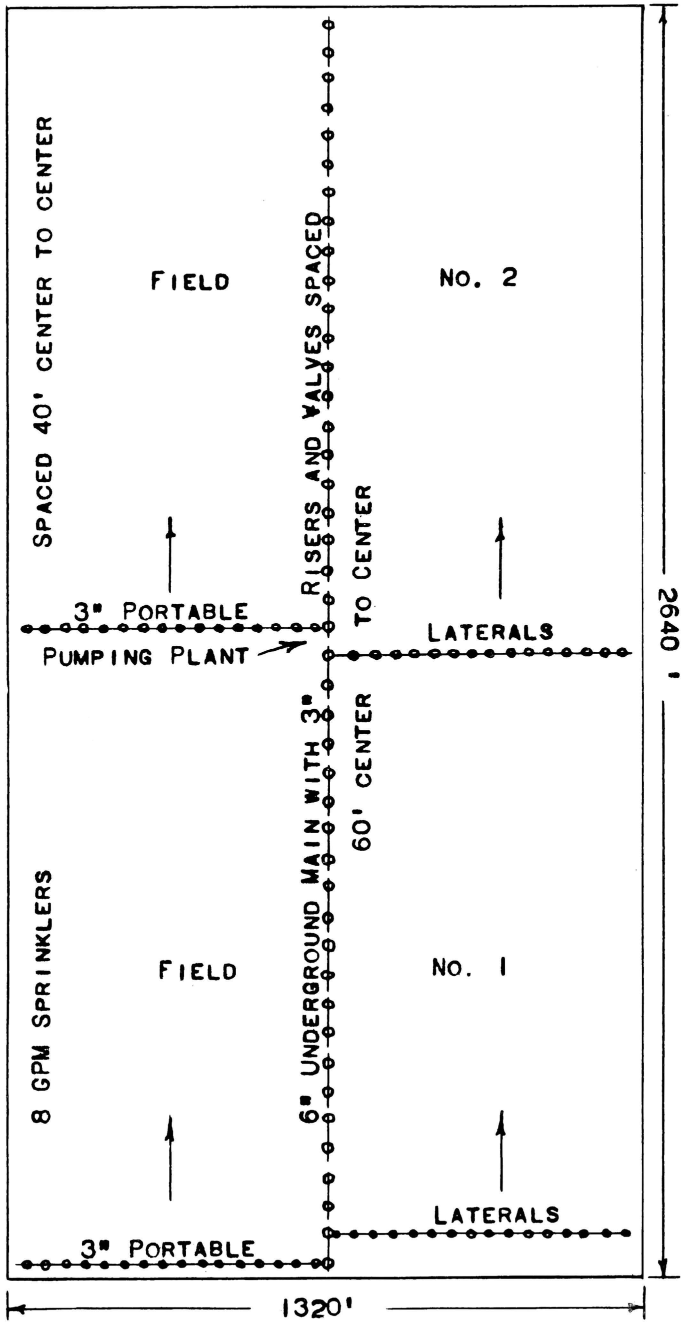


Fig. 21. Example of an 80-acre Semi-portable Rotary Sprinkler System.

Profits. Because conditions vary so widely and because of changing costs and prices, it is not often possible to find data on profits that can be transferred readily and with confidence to a new and different situation. In general it would appear that well-planned and well-executed supplemental irrigation will earn directly well over 100 per cent on the annual expense thereof and, in addition, will act as an insurance premium against the severe loss and interruption of the farm and livestock program caused by low yields and droughts. Truck and special crops are often the most profitable (see the References or visit farms near the larger cities) but they are too numerous and too variable to describe here.

Taking corn as an example of field crops, the average yearly irrigation may cost $15 or less per acre for surface irrigation (including interest, depreciation, taxes, insurance, labor, supplies, power, etc.). While the total cost of putting in the crop (including heavier fertilization and increased plant population) will be greater, the cost per bushel will not be greater since the yield will be increased.

In return for this annual expense, an average yearly increased yield should be secured of 30 bushels or more per acre. Col. C. R. Pettis (Reference 20f) and others believe that the increased yield will exceed this figure, attaining a total average yield of well over 100 bushels per acre. In addition, there would be assurance against droughts or low yields which interrupt the farm business, as for example, the livestock program. A farmer can no more afford these interruptions, such as are occurring in 1952, than can an efficient manufacturer.

The following quotation from Reference 14a, although not the latest and best practice, summarizes the experience with the irrigation of cotton, soybeans, corn, and lespedeza on silt loam rice soils in Arkansas. Early mistakes were corrected satisfactorily.

> "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 competely 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 $439.50 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. However, most of the reports are conservative since the full advantages of irrigation had not been obtained.

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 subdivide 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 probable that advice, and perhaps 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.

The establishment of a few typical owner-operated irrigated farms, under subsidy and technical advice of federal, state, and local agencies will greatly speed the growth and effectiveness of supplemental irrigation. Reference 14i explains such a modern setup which takes into account the whole balanced farm management program, not simply plot studies, and serves as a down-to-earth demonstration farm.

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, 14c, and 14i 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 haphazard, 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 II. PERCENTAGES OF NORMAL RAINFALL AND OF GOOD CROP YIELDS]

Year	Rainfall				[Annual Crop Yields]	
	March to May	June	July	August	Corn	All Tame Hay
1930	59	78	24	55	60	70
1918	108	67	42	89	65	70
1916	98	143	30	105	65	105
1914	64	48	67	114	75	50
1913	94	53	78	28	60	50
1911	73	37	100	110	85	45
1901	70	43	50	50	35	40
1894	88	80	62	41	80	70
1890	80	54	74	135	90	90
1887	78	91	58	89	70	90
1886	76	108	34	72	75	90
1881	80	114	38	42	45	95
1874	87	60	63	64	45	85
1873	103	88	62	45	65	90
1871	62	70	103	91	105	90
1870	58	34	64	189	95	70

"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 time 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 III. Percentages of Normal Rainfall and of Good Crop Yields in Recent Dry Years.

Year	Rainfall				Annual Crop Yields	
	March to May	June	July	August	Corn	All Tame Hay
1947	118	180	60	21	68	96
1945	164	171	105	41	79	97
1944	138	25	110	153	100	91
1941	79	98	145	102	85	89
1940	68	115	16	216	90	92
1939	113	105	32	76	87	92
1937	92	119	56	64	79	88
1936	50	05	16	91	23	55
1934	45	72	57	163	19	51

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 $\frac{1}{12}$ 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

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

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

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

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

1. **Practical Information for Beginners in Irrigation,** by Samuel Fortier. U. S. Department of Agriculture, *Farmers' Bulletin No. 864,* September, 1917.

   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.

2. **Irrigation Practice and Engineering, Vol. I,** by B. A. Etcheverry and S. T. Harding. Second Edition, McGraw Hill Book Company, 1933.

   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.

3. **Supplemental Irrigation in Humid Regions,** by F. E. Staebner. *Agricultural Engineering,* Vol. 18, pp. 165-8 and 170, April, 1937.

   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.

4. **Electric Power for Irrigation in Humid Regions,** by the Committee on the Relation of Electricity to Agriculture, Chicago. *Bulletin,* Vol. 7, July, 1937.

   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.

5. **Supplemental Irrigation on the Atlantic Coast,** by F. E. Staebner. *Agricultural Engineering,* Vol. 20, pp. 271-2 and 276, July, 1939.

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

6. **Supplemental Irrigation in Missouri,** by R. P. Beasley. University of Missouri Agricultural Experiment Station, *Bulletin No. 410,* August, 1939.

   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.

7. **Determining Index of Supplemental Irrigation and Its Application,** by F. E. Staebner. *Agricultural Engineering,* Vol. 21, pp. 215-7, June, 1940.

   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.

8. **Thirty Years of Supplemental Irrigation Studies,** by W. L. Powers *Agricultural Engineering,* Vol. 21, pp. 311-2, August, 1940.

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. 302,* June 1932.

9. **Supplemental Irrigation,** by F. E. Staebner. U. S. Department of Agriculture, *Farmers' Bulletin No. 1846,* October, 1940.

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.

10. **Truck and Pasture Irrigation.** Tennesse Valley Authority, Commerce Department, Agricultural Engineering Development Division, *Progress Report No. 1,* January, 1941; and *Progress Report No. 2,* January, 1942.

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.

11. **Farm Ponds in Missouri,** by Marion W. Clark. University of Missouri Agricultural Extension Service, *Circular No. 482,* January, 1943.

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

12. **Multiple Purpose Farm Ponds.** Missouri Conservation Commission. *Bulletin No. 15,* September, 1943.

Methods of constructing and using ponds.

13. **Handbook of Water Control.** California Corrugated Culvert Company, Berkeley and Los Angeles, California, 1943.

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.

14. **Land Development for Irrigation.** U. S. Department of Agriculture, Farm Security Administration, Denver, Colorado.

14a. **Irrigation of Arable Crops on a Rice Soil,** by R. P. Bartholowmew et al. Arkansas Agricultural Experiment Station, *Bulletin No. 455,* June, 1945, Fayetteville, Arkansas.

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

14b. **The Value of Supplemental Irrigation in Williamette Valley,** by W. L. Powers. Oregon Agricultural Experiment Station, *Bulletin No. 439,* August, 1946, Corvallis, Oregon.

A summary of results.

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

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

14d. **Irrigation For More Profits,** E. H. Davis, Irrigation Engineer, Georgia Agricultural Extension Service, University System of Georgia, *Bulletin 542,* Revised, June, 1948.

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.

14f. **Moisture Requirements in Agriculture - Farm Irrigation,** by Harry Burgess Roe. McGraw-Hill Book Company, 1950.

A general textbook treatment of irrigation.

14g. **Irrigation Principles and Practices,** by Orson W. Israelsen. Second Edition, John Wiley and Sons, 1950.

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

14h. **Report of the Steering Committee on Supplemental Irrigation,** by James Turnbull et al., Southeast Section, American Society of Agricultural Engineers, 1949. Mimeographed.

14i. **Frenchman - Cambridge Development Farm,** by various cooperating governmental agencies, Extension Service, University of Nebraska College of Agriculture, Lincoln, 1950.

This reference describes the most statisfactory type of an owner-managed farm developed and operated under the best available governmental advisory services. It serves as a demonstration and experimental farm taking into account the whole balanced farm management, not simply plot studies, and describes a full scale, over-all operation.

14j. **Irrigation, the Midwest's Newest Help,** by D. Hanson. *Successful Farming,* Vol. 48, pp. 44-45, August, 1950.

A good popular article.

14k. **A Practical Soil Water Meter as a Scientific Guide to Irrigation Practices,** by G. J. Bouyoucos. *Agronomy Journal, Vol. 42, No. 2,* February, 1950.

14l. **Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data,** by H. F. Blaney and W. D. Griddle. U. S. Department of Agriculture, Soil Conservation Service, *SCS - TP - 96,* August, 1950.

14m. **Irrigation Engineering, Vol. I, Agricultural and Hydrological Phases,** by Ivan E. Houk. John Wiley & Sons, 1951.

A general treatise on irrigation with little attention to supplemental irrigation.

14n. **Irrigation Reports of the Arkansas, White, and Red River Basins,** by the Inter-Agency Committee, 1951 and 1952. Mimeographed. Separate reports for Arkansas, Missouri, Oklahoma, and Texas.

These reports summarize the present and potential irrigation development in that portion of the states in the Arkansas, White, and Red River basins.

14o. **Climate in Relation to Planting and Irrigation of Vegetable Crops,** by C. W. Thornthwaite, The Johns Hopkins University Laboratory of Climatology, Seabrook, New Jersey, April, 1952. Prepared for the XVII International Congress, Section of Climatology, Washington, August, 1952.

A highly scientific treatment of plant growth, development, and water needs.

14p. **Turn Water Into Dollars,** by Associate Dean Paul W. Chapman, Georgia College of Agriculture. *The Progressive Farmer,* May, 1952, page 62.

An excellent popular treatment.

See also references 17, 20f, 24, 35, 35a, 44, and 45.

Special Crops

15. **Irrigation of Vegetable Crops.** *Gardener Chronicle* (London), Vol. 97, p. 389, January 15, 1935.

A brief summary of British practice.

16. **Influence of Irrigation on Important Small Fruits,** by W. S. Brown. Oregon Agricultural Experimental Station, *Bulletin No. 347,* pp. 1-37, June, 1936.

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.

17. **Farmers' Irrigation Guide.** U. S. Reclamation Bureau, *Conservation Bulletin No. 2,* 1939. Revised 1947.

18. **Irrigation Practices in Growing Alfalfa.** U. S. Department of Agriculture, *Farmers' Bulletin No. 1630,* 1940.

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.

19. **Orchard Irrigation.** U. S. Department of Agriculture, *Farmers' Bulletin No. 1518,* 1940.

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.

20. **Irrigation of Small Grain.** U. S. Department of Agriculture, *Farmers' Bulletin No. 1556,* 1940.

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.

20a. **Irrigation (Horticulture).** Georgia Agricultural Station, *Annual Reports, No. 58,* 1946, page 104, and *No. 59,* 1947, page 119.

20b. **Sprinkler Irrigation Costs for Vegetable Crops in the Willamette Valley, Oregon,** by M. H. Becker and D. C. Mumford. Oregon Agricultural Experiment Station, *Bulletin No. 463,* pp. 1-20, 1949.

A Comprehensive study of costs on 137 small acreages.

20c. **Value of Irrigation with Different Fertility Treatments for Vegetable Crops,** by L. M. Ware and W. A. Johnson. Agricultural Experiment Station, Alabama Polytechnic Institute, *Bulletin No. 276,* June, 1950, Auburn, Alabama.

Discusses in detail the cumulative effect of irrigation with increasing amounts of commercial and organic fertilizer. Results were satisfactory over a comprehensive 11-year experiment.

20d. **Irrigated Pastures in California,** by Burle J. Jones and J. B. Brown, revised by M. D. Miller and L. J. Booher. California Agricultural Extension Service, *Circular 125*, 1950, University of California, College of Agriculture, Berkeley.

More than 600,000 acres exist in California, using shallow rooted grasses and legumes.

20e. **Supplemental Irrigation for Pasture,** by R. W. Whitaker and W. F. Lytle. *Agricultural Engineering*, Vol. 32, pp. 163-5, March, 1951.

A five-acre plot in Southern Illinois shows promising results.

20f. **Are Little "Dry" Days the Real Corn Robbers?** By Glenn Cunningham. *Iowa Farm and Home Register*, December 2, 1951.

The theory of Colonel C. R. Pettis that short rainless periods during the crop season are costing Iowa farmers millions of bushels of corn in the average year. The article explains his newly developed theory of when and how much to irrigate, what crop losses occur nearly every year due to lack of rain, etc. It does not include his theories of the maximum yield that may be obtained under supplemental irrigation accompanied by increased plant population and the more intensive fertilization possible.

20g. **Irrigation for Truck Crops,** by John A. Campbell. Mississippi Agricultural Experiment Station, *Circular 163*, November, 1951, State College, Mississippi.

20h. **Irrigation of Vegetable Crops in Southeast Missouri,** by Isaac Jack Wahba. Master's thesis, University of Missouri, College of Agriculture, 1952.

A well planned and well executed, one-season experiment on 50 acres of very flat land, using modern methods. Rainfall is heavy but imperfectly distributed.

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

Pumping

21. **Pumping from Wells for Irrigation,** by Paul A. Ewing, revised by Carl Rohwer. U. S. Department of Agriculture, *Farmers' Bulletin No. 1404*, May, 1934, reprinted 1938.

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.

22. **Drought Hazard in Arizona Overcome in Irrigation Project with Pumps,** by R. Hornberger. *Western City*, Vol. 12, pp. 15-6 and 45-6, August, 1936.

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.

23. **Equipping a Small Irrigation Pumping Plant,** by W. E. Code. Colorado Agricultural Experiment Station, *Bulletin No. 433*, September, 1936.

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.

24. **Irrigation by Pumping from Wells,** by H. W. Gerlach. Iowa State Horticultural Society, *Transactions*, Vol. 72, pp. 360-2, 1937.

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.

25. **Small Irrigation Pumping Plants,** by Carl Rohwer and M. R. Lewis. U. S. Department of Agriculture, *Farmers' Bulletin No. 1857,* December, 1940.

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.

26. **Diesel Irrigation,** by W. H. Fullerton. *Diesel Progress,* Vol. 7, pp. 30-1, April, 1941.

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.

27. **Putting Down and Developing Wells for Irrigation,** by Carl Rohwer. U. S. Department of Agriculture, *Circular No. 546,* February, 1940, slightly revised March, 1941.

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.

28. **Gas Engines as Citrus Insurance,** by J. Medford. *Diesel Progress,* Vol. 8, p. 53, August, 1942.

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.

29. **Antelope Valley Farmers Profit from Irrigation,** by M. D. Pugh. *Diesel Power,* Vol. 21, pp. 713-4, August, 1943.

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.

30. **Design and Operation of Small Irrigation Pumping Plants,** by Carl Rohwer. U. S. Department of Agriculture, *Circular No. 678,* October, 1943.

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

30a. **Pumping for Irrigation,** by Ivan D. Wood. U. S. Department of Agriculture, Soil Conservation Service, 1950.

See also references 2, 4, 13, 20b, 36, 38, and 45b.

Surface Irrigation

31. **The Corrugation Method of Irrigation,** U. S. Department of Agriculture. *Farmers' Bulletin No. 1348,* revised October, 1931.

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.

32. **Porous Hose Irrigation,** by O. E. Robey. Michigan State College Extension Division, *Bulletin No. 133,* July, 1933.

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.

33. **Development of Porous Hose Method of Irrigation in Michigan,** by O. E. Robey. *Agricultural Engineering,* Vol. 15, pp. 382-3, August, 1934.

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

34. **The Border Method of Irrigation,** by Samuel Fortier. U. S. Department of Agriculture, *Farmers' Bulletin No. 1243,* revised October, 1937.

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.

35. **First Aid for Irrigator.** U. S. Department of Agriculture, Farm Security Administration, Office of Area Engineer of Water Conservation and Utilization, Denver, Colorado, May, 1943.

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.

35a. **Land Preparation for Irrigation and Drainage,** by Ivan W. Wood. Presented at the winter meeting of the American Society of Agricultural Engineers, Chicago, December, 1950.

Irrigation and drainage are combined at little additional cost in Iowa and elsewhere.

See also references 1, 2, 9, 14i, 17 to 20 inclusive, and 24.

Sprinkling

36. **Drought Protection by Spray Irrigation,** by K. Laux. *Engineering Progress,* Vol. 17, pp. 378-9, December, 1936.

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

37. **Irrigation by Sprinkling,** by J. E. Christiansen. *Agricultural Engineering,* Vol. 18, pp. 533-8, December, 1937.

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.

38. **Sprinkler Irrigation in Humid Sections of Oregon,** by F. E. Price. *Agricultural Engineering,* Vol. 19, pp. 161-2, April, 1938.

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

39. **Low Pressure Sprinkler Irrigation,** by F. W. Duffer. *Agricultural Engineering,* Vol. 20, pp. 97-8, March, 1939.

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

40. **Hydraulics of Sprinkling Systems for Irrigation,** by J. E. Christiansen. *Agricultural Engineering,* Vol. 22, p. 89, March, 1941.

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

41. **Hydraulics of Sprinkling Systems for Irrigation,** by J. E. Christiansen. American Society of Civil Engineers, *Transactions,* 1942, pp. 221-39, 240-50, 586.

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.

42. **Irrigation by Sprinkling,** by J. E. Christiansen. University of California, *Bulletin 670,* 1942.

42a. **Design of Sprinkler Irrigation Systems,** by Aldert Molenaar. State College of Washington, 1948.

43. **Design Procedure for Portable Sprinkler Irrigation,** by A. W. McCullough. *Agricultural Engineering,* Vol. 30, pp. 23-28, January, 1949.

44. **Sprinkler Irrigation,** United States Department of the Interior, Bureau of Reclamation. Revised December, 1949.

The latest general and fundamental treatment of the subject.

45. **Sprinkler Irrigation,** *Fortune Magazine,* June, 1950.

An up-to-date popular treatment.

45a. **Sprinkler Irrigation,** by Oregon State College, Corvallis; State College of Washington, Pullman; and University of Idaho, Moscow; 1952.

An excellent brief, popular treatment.

45b. **Commercial Irrigation Companies.**

Such companies will furnish literature, designs, estimates, and bids on sprinkling systems.

See also references 9, 13, 14b, 14c, 20b, and 24.

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