part of agriculture in the humid areas of the country. Experimental work and the experience of many farmers have proved that supplemental irrigation will produce additional yields of crops and pastures in most years in humid areas.

The economic question of whether the additional output will raise farm incomes enough to justify the higher costs is not so certain—benefits and costs vary greatly from farm to farm, and each farmer needs to appraise his own particular situation. But on an increasing number of farms the advantages are likely to outweigh the disadvantages. That means that irrigation in the East is likely to continue to expand—perhaps rapidly if farm prices are high but more slowly if prices are lower.

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Surface Irrigation Methods

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There are three general methods of applying irrigation water to the land.

In surface irrigation the soil is the reservoir from which the plants draw the water they need. The soil also conveys and distributes the water over the field.

In sprinkler irrigation the water is conveyed above the field in pipes, and the soil acts as a storage reservoir.

In subirrigation the water flows underground, and the capillary water moves upward toward the surface of the land to meet the needs of the crops.

Surface irrigation, with which this chapter deals, includes the general methods of flood and furrow and corrugation irrigation.

In flood irrigation, the water is permitted to cover the surface of the land in a continuous sheet. Theoretically the water should be standing at every point in the fields just long enough for the soil to absorb the whole amount of water needed to refill the root zone. But under practical field conditions it is seldom possible to meet the theoretical requirement completely—some parts of the field usually receive too much water if all parts receive adequate water. If the size of the irrigation stream is properly balanced against the intake rate of the soil, the total depth of water to be stored in the root zone, and the area to be covered by the stream, however, the results will be reasonably uniform and efficient.

FLOOD IRRIGATION includes several methods: Border strip, basin, contour or bench border irrigation, flooding from contour ditches, wild flooding, and border ditch.

The object of border strip irrigation is to advance a sheet of water down a narrow strip between low ridges or borders and to get the water into the soil as the sheet advances. The strip must be well leveled between the border ridges and the grade down the strip must be fairly uniform to avoid ponding. The ridges should be low and rounded so they can be planted with the strips and no land lost to production.

Border strip irrigation is well adapted for all close-growing crops and is used for some row crops, such as cotton. Hay and grain can be irrigated on uniform slopes up to 3 percent.

Established pasture can be irrigated on uniform slopes up to 6 percent. The method can be used on soils of coarse or fine texture. It utilizes large water streams safely. Its requirements as to labor and time are low. It provides for

uniform wetting and efficient use of water.

Basin irrigation is adapted especially to flat lands. It consists of quickly filling a diked area with water to the desired depth and allowing the water to percolate into the soil. It is desirable for close-growing crops and orchards on medium- to coarse-textured soils and for rice that is grown on fine-textured, slowly permeable soils. When the basins are properly graded and built to the right dimensions for the kind of soil and water supply, water can be applied efficiently and alkali can be controlled.

Contour, or bench border, irrigation is adapted to fairly uniform, moderate slopes with deep soils. Border strips are laid out across the slope on a controlled grade, and the ridges are constructed parallel to each other. If the strips are laid out on a grade, they operate about the same as does border strip irrigation. If the strips are short and level, it is like basin irrigation.

Flooding from contour ditches is used often on close-growing crops on sloping or rolling lands not subject to the degree of leveling necessary for other methods of irrigation. Water is flooded downslope between closely spaced field ditches running along the contour of the land. The ditches prevent the water from concentrating and causing erosion. Fairly uniform wetting is possible, but labor costs of irrigating are rather high. In general, this method should not be used if a more desirable method can be used.

In wild flooding, the stream of water is diverted from its course and allowed to spread out over the field at random. It is not recommended, because the low spots in the field will get too much water and the high spots will receive none.

The border ditch method is used in some of the older irrigated areas of the West, but it is not generally recommended. Parallel ditches 25 to 200 feet apart are run down the field in the direction of the land slope. The strips of land between the ditches are irrigated by diverting the water at intervals from either side of the ditch. The method uses water and labor inefficiently. The ditches often erode on the steeper slopes and silt full on the flatter slopes. They take a considerable area of land out of crop production and act as a weed nursery for the rest of the field.

FURROW IRRIGATION is the most common method of applying water to row crops. Water is applied in the furrows between the rows of plants. As water runs down the row, part of it is being absorbed all along the furrow and is moving through the soil to refill the moisture-storage reservoir of the soil under the growing plants. It is adapted to all row crops, truck crops, orchards, vineyards, and berry patches on gentle slopes on all but the coarser soils.

Cultivation of the furrows to control weeds keeps the soil loose. When the furrows run down the slope, serious erosion can occur unless the size of the irrigating stream is carefully controlled.

Furrow irrigation is usually expensive from a time and labor standpoint. Properly operated, it is fairly efficient in its use of water.

Contour furrow irrigation is an adaptation of furrow irrigation, in which the furrows are laid across the slope on a carefully selected grade. A reduction in the grade of the furrows makes them much less subject to erosion by irrigation water and rain.

CORRUGATION IRRIGATION is well adapted to close-growing crops on sloping and rolling lands and to soil slow to take water. The water is applied in small furrows running down the slope from the head ditch. The purpose of the furrows is not so much to carry the stream of water as to guide it. Some overtopping of the furrow may occur. Corrugation irrigation is suitable for fine-textured soils that take the water slowly and tend to seal over and bake when flooded. It provides uniform wetting and prevents erosive

water accumulation on land too rolling or steep for borders or basins and makes use of small irrigating streams. It is relatively expensive in labor.

A FARM DISTRIBUTION system is necessary to convey the irrigation water to the various fields from the point at which the water is available on the farm.

The system must be designed to carry enough water to meet the demands of the crop to each field without erosion and allow for efficient application. It must be laid out in accordance with good farm management practices. It must provide for conveying and regulating the irrigation stream and for the roads and drains that are needed. It must be located to give minimum interference with seeding, tillage, and harvesting.

OPEN DITCHES are the most common means of conveying irrigation water. In many areas the ditches to each field are permanently constructed and maintained. They form field boundaries and have permanent conveyance and control structures. Often their banks are seeded to perennial grasses to control weeds and provide extra stability. They usually have flat bottoms. Side slopes may be in the ratio of 1.5 to 1 or flatter, and are designed to carry the stream at a nonerosive velocity. Permissible velocities may be as high as 6 feet a second on shales and hardpans and as low as 1.5 feet a second in fine sands.

In areas where the seasonal requirements are low and only one or two irrigations are required, it is often wise to utilize temporary ditches for distributing the water to the fields. Such ditches are built with farm-type ditchers; they may have flat or rounded bottoms or a V cross section.

In medium- and fine-textured soils, side slopes are sometimes quite steep to reduce the overall width of the ditch and to facilitate the installation of temporary checks or other structures. These ditches are plowed in after the irrigation season is completed as a measure of weed control and to remove obstructions to harvesting operations.

Temporary ditches also are used for conveying the water from the edge of the field to the individual furrow or border. They are usually installed after the crop is planted, are used during the irrigation season, and are removed before harvest.

CONVEYANCE STRUCTURES of various types are usually necessary in open ditches to deliver water at the desired elevation on each field. Often an intervening low area between the water source and the upper part of the field requires the use of flumes or inverted siphons to carry the water across the draw or swale. These permanent structures should be well designed and constructed to fulfill their purpose and eliminate excessive maintenance.

When any minor depressions are encountered, a compacted earth fill is often placed and the ditch constructed on its top. Drainage water can be carried from one side of the embankment to the other by a culvert placed below the bottom of the irrigation ditch. Such installations, while relatively cheap to construct, pose problems of maintenance and are subject to damage from rodents and burrowing animals.

When ditches are constructed across porous soils, the loss of irrigation water by seepage may be serious. If so, permanent ditches may be lined with such less permeable material as clays or bentonites. The ditches may be lined with concrete or asphaltic concrete or may be sealed by means of a thin flexible membrane. Membrane linings are usually buried a few inches below the ditch surface to protect them from mechanical damage.

Important parts of any farm distribution system are the crossing structures, which permit the movement of machinery, produce, and livestock across the irrigation stream. Often they can be made a part of other structures. Sometimes culverts or bridges are provided.

CONTROL STRUCTURES placed in open ditches may be of many types. Their function is to measure the flow, provide a means of diverting the water from the ditch, or to lower safely the water from one elevation to another.

To make proper application of the water, the irrigator should know the size of the stream he is using. Measuring devices should be part of the distribution system and should permit the farmer to determine the flow being delivered to any point on his farm. Parshall flumes or weirs are often used for the purpose. Other structures in the system are sometimes calibrated so that reliable estimates of the flow may be made.

Water-control structures may be classified as division boxes, turnouts, and checks. Division boxes are used if the stream is divided into two or more sublaterals and may or may not be equipped with gates to control the flow. Turnouts provide a means of delivering water from the ditch to the area to be irrigated or into a temporary ditch. Checks are adjustable dams placed in the irrigation ditch to provide a means of controlling the depth of water serving the turnouts. Often it is advantageous to install structures that perform two or more of the functions.

Permanent ditches usually are equipped with permanent or semipermanent structures of concrete, masonry, timber, or metal. Temporary ditches usually have portable structures, which may be quickly installed or moved as needed.

Siphon tubes or spiles often are used to deliver the water from temporary ditches. The tubes, which carry water over the ditch bank by siphonic action, are made of a variety of materials in a number of sizes. Small tubes may deliver as little as a gallon a minute. The larger ones carry as much as 2 cubic feet a second. Spiles, or tubes laid through the ditch bank, also are commercially available for a similar range of flows.

A temporary check dam of a common type is made from a sheet of flexible plastic or canvas attached to a supporting rod or beam. The dam is placed across the ditch in such a way that the rod or beam rests on the ditch banks and the plastic or canvas material is tucked into the ditch side and bottom upstream. Such devices usually can be adjusted so that some of the flow may be carried downstream through a sleeve or over the top of the dam. Other types of temporary checks are made of sheet metal, pipe, fabric, or combinations of those materials.

Open ditches must carry the required flow of water without scouring. Erosion-control structures often are necessary to reduce the grade in the earth sections of the ditch. The structures have many forms and materials. A common type is a weir notch, equipped with an apron at a lower elevation so that the water may be dropped vertically to reduce the velocity of the water in the earth ditch to a safe value. Others consist of paved ditch sections on steep grades—often called chutes—or buried pipes, which will lower the water. Regardless of the type, the structure must be able to carry the required flow and provide for dissipation of the energy in the falling water before it enters the earth ditch section below.

Pipelines are usually more expensive to install but have advantages over open-ditches. Pipelines may be used to convey water by gravity alone or under pressure across a swale or to a higher elevation. They are essential when pressure is necessary to operate the system.

Permanent pipelines usually are buried and are equipped with necessary hydrants, relief stands, and other devices to control the water and protect the line. Permanent lines are commonly made of concrete, clay, asbestos-cement, or steel pipe. Plastic and aluminum pipe have become popular.

Portable surface pipes or hoses provide a good method of conveying the water to the field or to the individual border, basin, or furrow. They are

made of light materials—steel, aluminum, plastic, or canvas—and often are equipped with patented coupling devices for ease in connecting. They may be manufactured with small, adjustable gates, which permit the release of a small stream into each individual furrow.

Pipelines must be carefully planned to meet the requirements of the crop, fit the site conditions, and provide for economy of installation and operation. Because they eliminate losses from seepage and evaporation and provide excellent control of the water, they have found favor in many areas where water is scarce or expensive.

THE LAYOUT AND MANAGEMENT of the system needs careful planning as to soils and topography, intake rates and water-holding capacities of the soils, the amount of water that can be run in each furrow or border strip without causing erosion, and the relationship between length of run and size of irrigation stream to get the proper amount and distribution of moisture in the root zone.

Excessive irrigation wastes not only water. It also causes the leaching of water-soluble nutrients beyond the reach of the plants. Too heavy irrigation on higher land often causes waterlogging of rich, lower lands. Usually such a situation can be corrected only by a costly system of drains and reclamation.

How to apply irrigation water to crops without causing soil to erode is a big problem. Improvement in the fertility and structure of soil usually helps it absorb water faster. As the rate of intake increases, larger streams of water must be delivered to the furrows and borders to get uniform irrigation. Even though erodibility may be reduced by good soil management, the effect of the larger streams more than offsets any such gain. Thus the soil characteristics that influence irrigation methods are not stable. Conditions change from year to year with the cropping practices and even from irrigation to irrigation in a single season.

Theoretically it would be desirable to change the irrigation layout of a field at each successive irrigation for maximum efficiency. From a practical standpoint, continuously changing the length of run and spacing of furrows is not possible. Therefore the irrigation engineer, taking into account all of the influencing factors and the magnitude of change that might take place throughout the season and the rotation period, must choose practices that will be safe and reasonable for the conditions of the site.

Some suggestions are given for the layout and stream size generally most desirable.

FURROW AND CORRUGATION LAYOUTS are handled together because they are both subject to erosive action and both are thought of as generally carrying the water from one end of the field to the other.

The allowable size of streams on sloping lands largely depends on the slope at which the furrows are laid out. The general relationship of maximum allowable furrow stream and slope is $Q=\frac{10}{S}$, in which Q is the maximum nonerosive furrow stream in gallons per minute and S is the slope of furrow in percentage.

Thus, if the slope of the furrow is 0.2 percent, the furrow will carry 50 gallons a minute without serious erosion. With a slope of 2 percent, the furrow will safely carry only 5 gallons a minute.

With the flatter slopes, erosion probably will not be a factor—the carrying capacity of the furrow limits the size of stream that can be carried.

Maximum allowable length of run depends on several factors, including the maximum allowable stream size, the rate at which water is absorbed by the soil, and the amount of water to be stored each irrigation. The last two factors particularly vary throughout the season. The accompanying tabulation gives the values suggested for average conditions.

Spacing of furrows and corrugations sometimes can be varied within certain limits. Spacing greater than 30 inches generally is not desirable for most annual crops, because the root zone is so limited during much of the season. Of course many row crops are grown at a greater spacing and the furrow spacings are fixed.

In general, the coarser the soil, the closer the corrugations should be spaced for efficient irrigation, but spacings of less than 15 inches are seldom practical to construct and maintain.

Flow control from the field lateral to the individual furrows and corrugations is usually by siphons, spiles, or open cuts in the bank. For efficient and safe irrigation, however, positive controls are needed. Furrow streams of varying size do not give uniform application of water, and the larger streams may cause excessive erosion.

BORDER STRIP LAYOUT depends on the intake rate of the soil, the slope, and the depth of application.

The size of the border strip should not be greater than the maximum allowable or available stream will cover uniformly during the irrigation set, without excessive losses. The width is largely governed by the slope of the land and the amount of water that can be safely carried through turnouts to the strip. The length is limited by the size of stream per unit of width of strip that will flow without causing erosion.

For example, with slopes of 0.5 percent, a flow of 0.1 cubic foot per second per foot of border strip width may be safely used; with a slope of 2.0 percent, the safe value falls to about 0.035. Thus a longer run (length of border strip) is possible on the flatter slopes.

The height and shape of the border dikes are important. A common error is to build the dike too low to control the flow. The dikes must be higher for the flatter slopes than for the steeper ones. The base of the dike also should

usually be broad, so that farming operations can be carried on over the dike. Seldom should the sides of the dike be steeper than 2 horizontal to 1 vertical. Thus, on the steeper land where a minimum height of dike is 3 inches, the base would need to be at least 18 inches wide. On flatter lands where a 6-inch-high dike is needed, the minimum base width of the dike should be about 36 inches.

Properly constructed dikes allow for crop growth right over the dike and still control the flow of water during irrigation.

THE SIZE OF THE IRRIGATION stream depends on the soil, size of border strip, and depth of application. Soils of high intake rates require large streams to get the water over the land rapidly if excessive deep-percolation losses are to be avoided. Likewise for shallow irrigations large streams must be used. Small streams are desirable for deep applications.

The table on the next page suggests the relationship between size of stream needed to irrigate border strips of various sizes under different site conditions:

Control of flow into the border strips can be by open cuts in the bank of the field lateral, through open or pipe turnouts, or through siphons over the bank. In loose, sandy soils and in places where large flows are desirable, siphons that will carry up to 2.0 cubic feet a second each have been found useful. Such siphons require the use of

Border Irrigation Relationships for Various Soils, Slopes, and Depths of Application

Soil texture	*Slope of land*	*Depth of application*	*Suggested border-strip size*		*Size of irrigation stream*
			Width	*Length*	
	Percent	*Inches*	*feet*	*feet*	*Cubic feet per second*
Coarse	0.25	2	50	500	8.0
		4	50	800	7.0
		6	50	1,320	6.0
	1.00	2	40	300	2.75
		4	40	500	2.50
		6	40	900	2.50
	2.00	2	30	200	1.25
		4	30	300	1.00
		6	30	600	1.00
Medium	0.25	2	50	800	7.0
		4	50	1,320	6.0
		6	50	1,320	3.5
	1.00	2	40	500	2.5
		4	40	1,000	2.5
		6	40	1,320	2.5
	2.00	2	30	300	1.0
		4	30	600	1.0
		6	30	1,000	1.0
Fine	0.25	2	50	1,320	4.0
		4	50	1,320	2.5
		6	50	1,320	1.5
	1.00	2	40	1,320	2.5
		4	40	1,320	1.25
		6	40	1,320	0.75
	2.00	2	30	660	1.0
		4	30	1,320	1.0
		6	30	1,320	0.67

a priming pump, but are relatively easy to handle and positive in action. The investment in an adequate number of siphons to irrigate a large field is relatively small, compared to the cost of adequate permanent turnouts. The use of siphons lets the head ditch remain open, so that it can be cleaned by machines instead of hand labor.

BASIN IRRIGATION depends on using relatively small, level areas surrounded with dikes high enough to store the desired depth of water on the land. The irrigation stream is large enough to fill the basin quickly and then be turned into the next.

The basin dikes are often higher and steeper than those used with border irrigation, as it is not so common to farm over basin dikes.

Stream sizes desirable for basin irrigation should be considerably larger per unit of land area than with border irrigation. Possibly a good guide for the proper stream size would be to use at least twice as large a stream per unit of area as was suggested for the flatter grades with border irrigation.

Stream control to the basins is usually through some type of open or pipe turnout that has adequate capacity for the large streams required.

FLOODING FROM CONTOUR DITCHES is common practice on some of the

Furrow Irrigation Relationships for Various Soils, Slopes, and Depths of Application

Soil texture		Coarse				Medium				Fine			
		Depth of irrigation application, inches											
Furrow slope	Maximum allowable nonerosive furrow stream	2	4	6	8	2	4	6	8	2	4	6	8
		Maximum allowable length of run, feet											
Percent	*Gallons per minute*												
0.25	40	500	720	875	1,000	820	1,150	1,450	1,650	1,050	1,500	1,750	2,140
0.50	20	345	480	600	680	560	800	975	1,120	730	1,020	1,250	1,460
0.75	13	270	380	480	550	450	630	775	900	580	820	1,000	1,150
1.00	10	235	330	400	470	380	540	650	760	500	750	850	990
1.50	7	190	265	330	375	310	430	530	620	400	570	700	800
2.00	5	160	225	275	320	260	370	450	530	345	480	600	675
3.00	3	125	180	220	250	210	295	360	420	270	385	470	550
5.00	2	95	135	165	190	160	225	270	320	210	290	350	410

older irrigated lands of the West, where the topography is rather rough. The contour ditches should be set with practically no grade if they are not too long. For longer ditches, a slope of 0.1 foot per 100 feet is usually adequate and is easier to handle.

Spacing between contour ditches should not be too great. With fine-textured soils on grades of 1 to 2 percent, the spacing should not exceed 250 feet. On the same grades, ditch spacing on the coarser soils should not exceed 100 feet. For 5-percent slopes, the distances should be 150 feet and 50 feet, respectively.

The size of stream required at any one turnout along the contour ditch need not be large, because the area of land such a stream is expected to cover will be small. The stream sizes, per unit of area, suggested under border irrigation generally apply to the contour ditches.

Flow control from contour ditches is often by cuts in the ditch banks, particularly if the banks are sodded. Siphons have been satisfactory in some localities.

Specifications for surface irrigation methods cannot be entirely rigid.

Many of the factors affecting the relationships of length of run, the size of stream, and spacing of corrugations vary widely throughout the irrigation season and throughout the crop rotation period. The foregoing specifications, however, will satisfy average conditions when good farming is practiced.

BORDER STRIP irrigation generally will not function properly when the slope in the direction of flow is more than 2 percent. Pasturelands sometimes utilize borders on steeper grades up to about 6 percent, but the distance between border ridges must be reduced to about 10 to 15 feet. The steepest downfield slope on any one border strip should not be greater than twice the flattest, and the grade should either increase or decrease consistently from one end to the other without undula-

tion. A cross slope as much as one-tenth of a foot is allowable within an individual border strip; that often provides the limiting factor for the width of border strips. For example, a field with a cross slope of 0.2 percent could not have border ridges more than 50 feet apart.

Corrugations can be successfully used on slopes as high as 8 percent in places where runoff from rains is not a serious problem and where the irrigation water is carefully controlled. The slope of the corrugation within the run should not undulate. When the grade increases down the field, the steepest portion should not have a slope greater than twice the flattest, and the total change should not exceed 2 percent. When the grade decreases, the steepest part should not be more than one and one-half times the flattest, or a total change of 1 percent. If the grade of the corrugation is more than 2 percent, a cross slope as high as 0.5 percent may be permitted, but on flat grades the cross slope should not be greater than one-fourth the down-field grade.

Furrows, like border strips and corrugations, should not have an undulating profile. They may be used on slopes up to 3 percent when erosion from rain is not a problem. The steepest grade in the profile on increasing slopes should not be greater than twice the flattest; on decreasing slopes, the steepest should be less than one and one-half times the flattest.

The maximum allowable cross slope depends on the depth of the furrow. When furrows are about 9 inches deep, cross slopes up to 8 percent are satisfactory on fine- and medium-textured soils. On coarse-textured soils, the upper limit of cross slope is 5 percent; on very coarse soils it is 2 percent. With medium-depth furrows, 6 inches, the allowable cross slopes are 3 percent, 2 percent, and 1 percent, respectively, for fine or medium, coarse, and very coarse soils. Shallow furrows, 3 inches, may have cross slopes of 0.5 percent on medium and fine soils and 0.3 percent on coarse soils. These requirements are very important when the contour irrigation is the method to be used.

Basins or level borders require grades less than 0.1 percent with no cross slope. If contour levees are used, such as in rice basins, the land slope should not exceed 1 percent, and the levees should be spaced so that the vertical interval between dikes is not more than 3 inches.

Surface irrigation should be supplemented with a complete water-disposal system to remove waste waters and to eliminate unwanted ponding. The drains should be designed to carry off short, peak flood flows as well as irrigation waste water. Provisions are needed to allow basins or levee systems to be drained when desired. Drains often need some protection—vegetation or some structure, to carry the water without erosion. Drains should be equipped with crossings so that farm equipment can be moved over them.

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