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**SCS**
**National**
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## Section 15

# IRRIGATION

## Chapter 3

# PLANNING FARM IRRIGATION SYSTEMS

**Soil Conservation Service**
**United States Department of Agriculture**

SCS NATIONAL ENGINEERING HANDBOOK

SECTION 15

IRRIGATION

CHAPTER 3--PLANNING FARM IRRIGATION SYSTEMS

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# SCS NATIONAL ENGINEERING HANDBOOK

# SECTION 15

# IRRIGATION

## CHAPTER 3--PLANNING FARM IRRIGATION SYSTEMS

### Introduction

#### Proper Planning Permits Conservation Irrigation

Conservation irrigation is the use of irrigated soils and irrigation water in a way that insures high production without wasting either water or soil. It means using cropping, irrigation, and cultural practices that maintain the land in permanent agriculture. To an irrigator conservation irrigation can mean saving water, controlling erosion, better crop yields, lower production costs, and continued productivity of his irrigated land.

One of the major factors in conservation irrigation is a properly planned conservation farm irrigation system. A conservation farm irrigation system is the complete arrangement of the delivery and application facilities needed to distribute irrigation water efficiently to all land served by the system.

A farm irrigation system consists of three parts--delivery, application, and disposal (fig. 1). The delivery part consists of the facilities needed to convey irrigation water from the source of supply to individual fields and includes supply ditches and pipelines, valves, hydrants, flumes, measuring devices, turnouts, and checks. For the application and distribution of water on a field, head ditches, distribution pipelines (buried or surface), valves and hydrants, gated pipe, siphon tubes, sprinkler lines, and sprinkler nozzles and equipment must be planned. Tail-water or collection ditches, sumps, and any other facilities needed to collect and safely dispose of, or recover for further irrigation, any waste water and storm runoff make up the disposal part of the system.

Few, if any, farm operating units have identical physical, economic, and managerial conditions. Careful and adequate planning is necessary if the irrigation system is to meet the requirements of the farm operating unit on which it is to be used. It must fit the soils, crops, climate, water supply, and farming operations. To be adequate, a system must have the capacity to meet the peak-use requirements of the crops to be grown (chap. 1) and to deliver water at the rate required for the irrigation method used. It should be planned and designed to operate at high efficiency to conserve irrigation water.

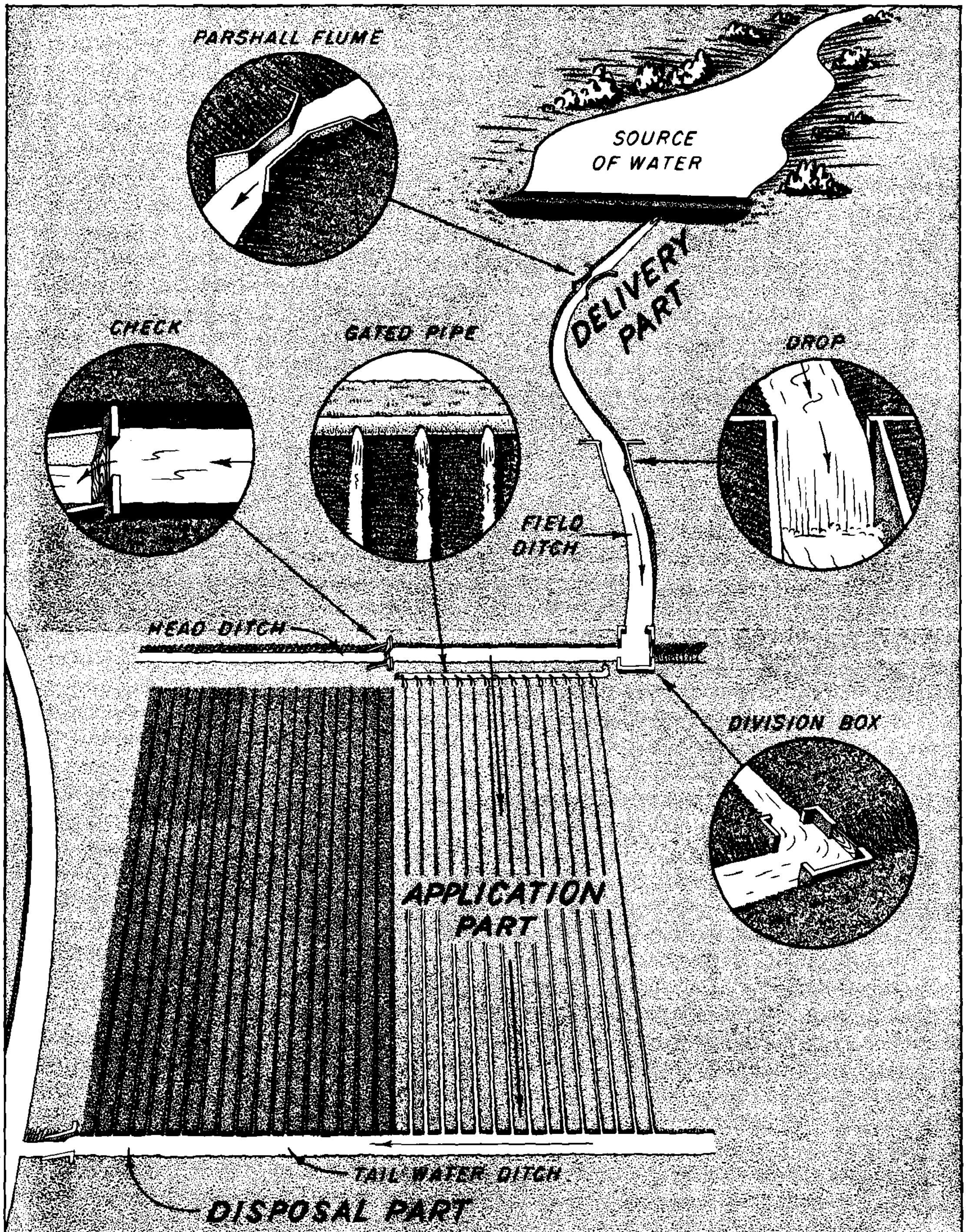


Figure 3-1.--A farm irrigation system.

## Preliminary Considerations

For an irrigation system to function as planned both irrigator and planner must know and agree on some things before they spend much time in planning.

### What the Irrigator Should Know

Conservation irrigation, like other farm operations, must be undertaken only if it can be done successfully and at a profit. In other words, the benefits from irrigation must increase farm income enough to cover all costs of purchasing, installing, operating, and maintaining the irrigation system and provide a reasonable return from the owner's investment.

Water is only one of several limiting factors in producing high yields of any crop. An irrigator should know the capability of his land under irrigation. He should know the soil management practices necessary to maintain good tilth and fertility. He should be willing to use the best adapted crop variety and the plant population that will produce the best yields and to have an adequate system for controlling plant diseases and insects. He should understand and be willing to practice irrigation water management.

Irrigation Water Management.--Conservation irrigation water management means controlling or regulating water application in a way that insures high crop yields without wasting water, soil, or plant nutrients. It means applying water according to crop needs in amounts that can be held in the soil available to crops and at rates consistent with the intake characteristics of the soil and the erosion hazard of the site.

An irrigator must have a reasonably good understanding of the basic principles of conservation irrigation. He must have a general idea of how water is held in the soil and released to plants and how much water his soils hold. He needs to know how to determine when to irrigate and how much water to apply. He needs to have a general understanding of soil-intake characteristics and of the adjustments in stream size and time of water application needed to fit the intake characteristics of his soils (chap. 1).

### What the Planner Should Know

It is impossible to design an effective conservation irrigation system without complete understanding by both irrigator and planner. There should be mutual understanding of the water supply needed. The planner must know the farmer's wishes. He must consider the entire farm even if only one field is to be planned for irrigation at any one time.

Adequacy of Water Supply.--The first things to consider are availability, quality, and adequacy of the farm water supply. If there is no adequate supply or no possibility of developing one, further planning is a waste of time for both farmer and planner. Successful irrigation is not possible without a water supply adequate for the crops to be grown.

Farmer's Preferences.--Each farmer has a preference as to the kind of farm enterprise he wishes, which may dictate the kind of irrigation system and application method. He may have strong feelings about one application method over another. He may also be restricted by finances, availability of labor, and availability of construction materials and equipment. The designer should know how many hours per day the system is to be operated since this affects its design. No matter how technically sound a plan is, it cannot be effective if the farmer does not have confidence in the plan or the ability or desire to put it into operation.

Consider Entire Farm.--Seldom can all the irrigation facilities for an entire farm be established at one time. Usually specific fields or areas are planned individually, and establishment of an entire system takes several years. Fields or areas planned without considering the surrounding fields or areas may not fit in with future expansion. When these new areas are developed, it may be necessary to rework existing areas to make them a part of the overall system. This is costly and can be avoided if the planner studies the entire farm before planning any part of it.

Locate the high points in a field and determine the direction of irrigation and drainage. Determine the soil boundaries, probable crop rotations, and feasibility of land leveling. Locate field boundaries and farm roads. From this preliminary plan it should be possible to determine the best delivery point for the water.

## Planning Procedure

After a preliminary plan has been made, studied, and discussed with the farmer, detailed plans for any area on the farm can then be prepared. First, select a method of water application for each field and prepare a layout. Then design the delivery, application, and disposal facilities as well as the necessary access roads.

### Select Method

Determine the method or methods of water application best suited to each area or field. Several methods of application can be used on some sites and only one method on others. If more than one method can be used, study and evaluate each as to efficiency of water application and arrangement of irrigation units and other necessary facilities. In this way the method that best fits the fields and crops and is agreeable to the farmer can be used.

### Layout

Planning a general layout for subdividing and irrigating the area in units of suitable dimensions is the next step. Areas delineated according to slope and soil characteristics provide a basis for selecting the best field arrangement and for locating field ditches.

Here again consider alternate layouts. Some layouts are more expensive than others and some are more suitable than others. Some desirable but costly layouts may not be justified because of the farmer's financial resources or because of the low-value crops that are a part of the farm enterprise.

Application

Next design the application facilities. You can determine the amount of water that must be applied in a normal irrigation, the time allowed for applying it, and the rate at which it can be applied from the local irrigation guide. Then determine the amount of water that must be delivered to a field. Plan for land leveling if it is needed. Locate and design the head ditch or pipeline to fit the method of irrigation used. Locate and design ditches, pipes, levees, and the other structures needed to apply water to the field in the amount and rate required by the crop and soil.

Delivery

Plan the delivery facilities so that they permit delivery of water to the different fields in the volume and rate required by the method of application previously selected. Select and design the method of conveyance, either ditch or pipeline. Locate and design all the necessary grade-control and distribution-control structures, including measuring devices.

Disposal

Plan for the disposal of any irrigation waste water and excess rainfall promptly and safely. Consider recovery of waste water for reuse. Include all necessary disposal facilities--ditches, pipe, tile, structures, and pumps.

## Factors in Planning

A well-designed conservation irrigation system delivers the required amount of water to all parts of the area to be irrigated at the required rate without damage to the soil or excessive loss of water. It is accessible and easy to operate without obstructing other farming operations. To plan such an irrigation system you must know the many factors that affect design in the area to be irrigated. Study such factors as soils, topography, crops to be irrigated, water supply, existing facilities, and available construction and farm equipment.

Soils

Soil is the foundation on which a conservation irrigation system must be built. It must be irrigable, that is, capable of sustaining yields high enough to pay the costs of development plus those of farming operations and maintenance. A farmer must be able to get a profit from irrigation without soil deterioration.

A soil survey is essential to irrigation planning. It is the basis for determining if the soils are irrigable and is used by the planner to fit the system to the soil. The location and extent of soils that differ widely must be considered in deciding how an area can be subdivided, if necessary, so that suitable application methods and required amounts of water can be determined. The most important soil characteristic is its ability to take up and retain water. Other soil conditions that affect planning of irrigation should be noted, such as high water table, restrictions to drainage, erosion hazard, plowsoles and compacted areas, and high salt content.

To evaluate soil characteristics a knowledge of the physical properties of soil and how they affect the design and operation of irrigation systems is needed. Soil-plant-water relationships are discussed in chapter 1.

### Intake Rates

You must know the rate at which water enters a soil under the varying land use and cropping conditions that may occur during the period when irrigation water is to be applied. Surface sealing, compaction, soil and water salts, sediment in irrigation water, soil erosion, land leveling, tillage practices, and other factors affect the intake rate of any soil. Any one or a combination may be present. These factors must be evaluated in determining the design intake rate.

The intake rate of a soil affects the method of water application, length of run, and time of application, which in turn affects the cost of a system. You must know the rate at which water passes through a soil to evaluate the possibilities for leaching and subsurface drainage. The ratio of lateral movement of moisture to downward movement is also important in selecting and designing some methods of water application.

### Water-Holding Capacity

You must know the amount of water a soil can hold available to plants. The water-holding capacity limits the amount of water that can be applied at any one irrigation. For a given crop a soil with low water-holding capacity requires smaller and more frequent irrigations than a soil with high water-holding capacity. This is one factor in determining the number of days that can be allowed for applying irrigation water and hence is one basis for capacity and equipment design. The irrigation system must be designed so that water can be applied over the entire field before all the available stored moisture in any part of the field is used by a crop (chap. 1).

### Depth

For irrigation soil depth is the depth from which a plant extracts moisture. A soil that permits normal root development and penetration provides maximum water storage. Restricting layers, such as rock, severely compacted layers, sand lenses, or a high water table, affect the moisture-storage capacity.

### Other Characteristics

The depth to and thickness of layers having important textural or structural differences are important in design. Texture is closely associated with workability and feasibility of using a soil for constructing earthworks such as ditches and dikes. Soil permeability is important in locating and building canals and reservoirs. Impermeable or very slowly permeable material affects construction costs and the type of construction used. Natural density of soil material and response to compaction is used in estimating the adjustments needed to balance cuts and fills for land leveling and in selecting material for the earth structures that may be required to support loads or restrain water movement.

It is highly important in land leveling to know the soil profile conditions and the maximum cut that can be made without seriously affecting agricultural production. If leveling will expose large areas of infertile subsoil, it may not be advisable to level the land for surface methods of water application and sprinklers may be needed instead. Exposing a small amount of infertile subsoil in a few small areas generally is permissible in leveling, especially if the improvement of an entire field depends on this exposure. The feasibility of restoring exposed subsoil to an economic level of productivity should be considered. Some subsoils respond quickly to needed soil-management treatments and others do not. But exposing a few nonproductive spots by grading usually is outweighed by the advantages of having a field properly leveled for efficient water application. If it is necessary to remove much topsoil in leveling, it may be advantageous to stockpile it and respread it on the exposed subsoil.

## Drainage

Good drainage, both surface and internal, is essential to successful irrigation. If the land is not naturally well drained, artificial drainage must be established before or at the same time the irrigation system is installed. To plan a satisfactory irrigation system you must have a working knowledge of drainage.

In humid areas subsurface drainage is highly important if the soils are permeable enough for subsurface drains to be effective in lowering the water table to the depth required for good growing conditions. Surface drainage is always needed to remove excess runoff. Wet soils that delay planting in the spring, impede crop growth, and delay harvesting cannot be irrigated successfully.

In arid areas removing excess irrigation water, particularly ground water, is a primary function of drainage. Water lost through deep percolation increases the amount of ground water in a soil and may cause the water table to rise to a level at which crops are damaged. Subsurface drains are then necessary. Runoff from precipitation is usually small in arid and semiarid regions, and disposal ditches for any irrigation waste water are often adequate for disposing of any surface runoff from the low precipitation. Subsurface drainage may be needed to prevent or modify saline-alkali conditions in a soil by leaching.

Seepage from irrigation ditches can damage land and waste water. If site conditions require conveying water across gravelly, sandy, or other excessively permeable areas, the irrigation system design must provide for pipelines, flumes, or lined ditches as needed to prevent loss of water by seepage into the soil. Proper seepage control reduces the need for drainage. For additional information on drainage see section 16 of the National Engineering Handbook.

## Erosion

Erosion, by either irrigation water or rain, can be a hazard to the operation and maintenance of an irrigation system. Furthermore, high yields of irrigated crops cannot be maintained on eroding land. Irrigation should not be planned for land subject to erosion until erosion control measures have been established or are provided for in the farm irrigation system. Erosion control practices and the irrigation system need to be fitted together for ease of operation and uniform distribution of water. Some soils are more susceptible to erosion than others. You must know the erodibility of the soils to be irrigated and then evaluate the factors that cause erosion and allow for them in planning the irrigation system.

Water erosion may be caused by the irrigation stream, runoff from adjacent areas, or water that falls directly on the irrigated area, either as rainfall or from sprinklers. You must provide for conveying and distributing irrigation water without damaging erosion. All unlined ditches must be located on nonerosive grades. If water must be carried down slopes steep enough to cause an excessive flow velociy, you must provide for erosion control structures, such as drops, chutes, buried pipelines, or erosion-resistant ditch linings in the design. Where flumes, chutes, or pipelines designed for high-velocity flows discharge into unlined ditches, you must plan stilling basins or other energy-dissipating devices.

The rate at which water is applied must be controlled so that it does not cause erosion. Some movement of soil particles always occurs when water flows over loose bare soil. If stream size is adjusted to the slope, erosion can be kept to a minimum for surface irrigation. In some areas it is rainfall amount and intensity and not irrigation stream size that governs the control measures used.

If sprinklers are to be used, you must design the rate of application so that it does not cause runoff that adds to the erosion hazard. This is particularly true in humid areas where a heavy rainstorm immediately after an irrigation may cause excessive runoff. Size of the drops from the sprinklers also is important. Large drops dislodge particles of soil that can easily be carried away by runoff water. On bare fields, new seedings, and row crops, rain or sprinkler irrigation may compact and seal the soil surface. This reduces water absorption and increases the erosion hazard. A crop cover or mulch dissipates the energy of falling water, and there is little or no surface sealing or erosion. In areas where the rate of precipitation is likely to exceed a soil's intake rate, runoff and erosion may be a problem. This problem usually can be handled by installing conservation practices such as changing land cover, degree of slope, or length of slope. If runoff from adjacent areas is likely to cause erosion or flooding, plans must be made for either the diversion or controlled conveyance of the runoff water.

Winds damage crops, soil, topography, and irrigation structures and may affect the distribution of irrigation water. In areas where strong winds blow during the growing season, it is often necessary to establish remedial measures.

Winds may remove surface soil or deposit soil material on other areas. Soil removal can usually be reduced by vegetation, wind strips, tillage, or shelter belts. But these measures may lead to soil accumulation if adjacent areas are not similarly protected. Therefore, you must not only determine the probability of wind erosion on the area to be irrigated but also consider conditions on adjacent areas before selecting an irrigation method. Since canals, ditches, and other open structures may be rapidly filled by windborne materials, consider using closed conduits where this hazard exists.

Earth embankments, such as dams, canal banks, and border ridges or levees, may be damaged by wave action if long open reaches are parallel to the prevailing wind direction. This hazard can be overcome by locating these structures so as to reduce the fetch or by using riprap and other protective measures such as false berms or baffles.

Saline or Alkali Conditions

Saline or alkali soils require special irrigation planning. Selection of crops, fertilizer requirements, and the need for leaching and soil amendments must be considered. There may be some limitations on water-application methods that can be used.

Saline and alkali soils are generally restricted to arid regions where there is not enough rainfall to leach salt from the soil. But in areas where brackish water is used for irrigation, the soils may also show effects of salt accumulation.

Saline soils ordinarily are slightly alkaline in reaction (pH 7.0 to 8.5) but contain very little adsorbed sodium. They can often be recognized in the field by white salt crusts on the surface, by a damp oily-looking surface devoid of vegetation, by stunted crop plants that vary considerably in size and have deep blue-green foliage, and sometimes by tipburn and firing of leaf margins. To assess soil salinity, however, chemical and electrical-conductivity measurements must be made.

An alkali soil may be highly alkaline but not contain excessive amounts of soluble salts. These soils correspond to "black alkali" soils and often occur in small irregular areas called "slick spots." Sodium usually is the dominant cation in alkali soils.

A saline-alkali soil contains excessive amounts of both soluble salts and adsorbed sodium. As long as they contain excess salts, these soils usually are similar in appearance and properties to saline soils. If the excess soluble salts are leached out, the soil properties may change markedly and become similar to those of alkali soils. They become strongly alkaline, soil particles disperse, and the soils become unfavorable for the entry and movement of water and gases and for tillage.

A high salt concentration in the soil solution interferes with the ability of a plant to absorb both moisture and plant nutrients from the soil. If too high in the root zone, it is detrimental to plant growth regardless of the kind of salt present. Small quantities of some salts may reduce yields of sensitive crops and only slightly larger amounts may prevent crop growth. Some alkali salts cause undesirable changes in the physical condition of soils, reducing permeability and increasing the difficulty of cultivation.

Saline soils can be improved by leaching--applying extra water to a field and allowing it to soak through the soil, draining the salts away. Alkali soils can be improved by adding chemicals such as gypsum or sulfur, leaching the soil, and then using practices that build soil structure. Saline-alkali soils can be improved in the same way. Usually it is best to apply the chemicals before leaching.

## Topography

Topography is a major factor in determining the feasibility of irrigation, selecting the method of irrigation, estimating the number and kind of water-control structures needed, and determining the need for land leveling. The relative elevation of the water source, the land surface between the water source and the area to be irrigated, the different parts of the area to be irrigated, and the drainage outlets are the important topographic features that must be known to properly plan a farm conservation irrigation system. You may be able to learn enough by a simple inspection, or you may need to make a survey. Detailed surveys are generally needed to design a system.

The kind of topographic survey needed depends on the irrigation method to be used and irregularity of the ground surface. Since detailed topographic surveys are time consuming and expensive, get only enough information to permit sound and accurate planning. Any topographic survey begins with a base map that shows boundaries and dimensions of the fields to be irrigated and location of the water supply. Such a map can be made by tracing an enlarged aerial photo, usually at a scale of 50 to 200 feet to the inch.

The general topographic information needed for planning most irrigation systems and methods of application includes as a minimum the following:

1. Source and elevation of the water supply for the area under consideration

2. Landscape features, such as fences, buildings, roads, and shelterbelts, that influence the layout and design of the system
3. Present field boundaries
4. Drainage pattern of the farm, including outlets

Additional topographic information needed depends on the method of water application.

Sprinkler Irrigation

For planning sprinkler irrigation systems, the following additional topographic information is generally needed:

1. Direction of land slope to locate laterals and main lines
2. Changes in elevation along lateral-line settings to design a system that controls variations in sprinkler discharge
3. Maximum differences in elevation along the main line and between the irrigated area and the water source

If slopes are gentle and fairly uniform, checking the elevation at a few points along the side of the field, at control points along possible main-line locations, and at the water source is enough. On rolling land or if crop rows must be on the contour, or on level land where surface drainage is a problem, a more detailed survey is needed, including a contour map of the area to be irrigated.

Surface Irrigation

For surface methods not requiring land leveling, a less detailed survey will suffice. Generally about all that is needed is the elevation of natural ridges, depressions, and other features that influence location of contour ditches, field supply ditches, and drainage ditches.

If water is to be applied by graded borders, furrows, or other surface methods requiring land leveling, a complete topographic survey is required. It must show the slope and surface features needing correction by land leveling as well as the direction of irrigation.

Subirrigation

If a field is to be subirrigated, you must know the general topography to locate water-application conduits and water-level-control structures. The intensity of survey needed varies with location. For nearly level uniform fields you need only those elevations that show the general slope, ridges, and depressions. For other fields a topographic map may be needed, particularly if land leveling is needed to keep the water table at the same depth between distribution ditches or tile lines.

Supply Lines

If open ditches or permanent buried pipelines are to carry water from the source to the field supply ditches, determine their location by standard route-type survey. You need a profile of each proposed centerline and, to compute the amount of excavation needed, a cross section also.

Conservation Practices
If terraces are to be used with sprinklers or contour furrows, you need enough topographic information to lay out the terraces and to locate and plan the terrace outlets. If contour bench leveling is proposed for reducing grade on a field where steep slopes make surface irrigation difficult and hazardous, you need detailed topographic information (chap. 12, Land Leveling).

Water Supply

A supply of water adequate for the needs of the crops to be irrigated must be available when needed. Water supply is often the controlling factor in irrigation feasibility and the number of acres that can be irrigated. Make a detailed inventory before planning to make sure that the available water supply is adequate. Find out the possible sources and the rate, quality, and quantity of water available at each location. Determine seasonal variations in supply as well as those during the growing season. You may need to study the supply by months or shorter periods in relation to crop requirements. The irrigator's water rights should also be known.

Water Rights
Water rights are the legal means by which water can be used. In areas covered by legislative codes, the procedures for acquiring water rights have been devised primarily to protect their owners. In areas not covered by legislative codes, it is advisable for a water user to establish the initial date and amount of appropriation, the point of diversion, and the period of use by witness affidavit in a form acceptable to a court or jurisdiction in the event of water legislation or suits contesting water rights.

The eastern part of the United States is not covered by legislative codes, but water use is based upon the riparian principle. Under this principle, owners of land touching a stream have equal rights to use of the water. Other landowners do not have such rights. The riparian owner has the right to have a stream flow past his land substantially unimpaired in quality and undiminished in quantity by water users above him. Each riparian landowner, however, may make reasonable use of the water for domestic or other purposes. All domestic uses must be satisfied before any water can be taken for nondomestic uses. What is reasonable use depends on supply, kind and means of use, and other circumstances at the particular time and place. Because riparian rights are not well defined, investments in water development based on riparian rights are not as dependable as they should be. Ground-water rights are based on both court decisions and legislative acts. Ground-water rights vary by State and often do not offer much protection.

All the 17 Western States have prior-appropriation laws. Under this principle the first or earlier user of water for a beneficial purpose has the best right. His right is specific as to time, place, and amount. The right of others to use water from a source is subject to the right of the prior user. In times of shortage any reduction to users is in the reverse order by which water rights were obtained. Therefore in the West, if an irrigator has a water right, it is usually good to the extent of his priority and most water rights are well defined.

Procuring or establishing water rights is a responsibility of the water user.

Quantity

The quantity of irrigation water required for any particular period should equal or exceed the gross irrigation requirement for that period. To this amount must be added any water required for leaching, temperature control, or frost control.

In addition to the total amount of water required, rate of delivery is an important factor in designing and operating an irrigation system. Soil moisture must be replaced before crop production is reduced by the lack of available moisture in the soil. The rate of delivery per unit of area must be equal to the gross application per irrigation for the specified operating time.

Rate of delivery can be computed by the equation

$$Q = \frac{453\,Ad}{FH}$$

where Q = rate of delivery in gallons per minute

A = acreage of design area

d = gross depth of application in acre-inches per acre

F = number of days allowed for completion of one irrigation

H = number of actual operating hours per day

Factors (d) and (F) can be obtained from the local irrigation guide. Factors (A) and (d) are set, but F and H can be varied according to a farmer's wishes. The guide gives the maximum number of days that can be allowed for completing one irrigation (F). The number of actual operating hours per day (H) must be the farmer's decision. He may wish to irrigate his acreage in less than the allowable number of days or he may have labor available for only part of a day.

Delivery may be continuous, on demand or modified demand, or at fixed intervals (rotation). Demand or modified demand schedules of delivery are preferred. Continuous and fixed schedules of delivery do not give enough consideration to variations in rainfall and consumptive use. But for some crops and irrigation systems demand delivery may be the same as continuous for most of the irrigation season.

In determining the net irrigation requirement, calculate consumptive use for the crops to be grown. The net irrigation water requirement for a crop is total consumptive use of the crop less effective growing-season rainfall, carry-over soil moisture from winter rains, and any moisture from ground water. By applying the expected field application efficiency to the net irrigation water requirement you arrive at the gross field requirement. To this figure add expected water losses from the source to the point of application and any amount needed for leaching, temperature control, etc., to get the total quantity of irrigation water needed. Consumptive use, effective rainfall, carry-over soil moisture, and irrigation efficiency are discussed in detail in other chapters of section 15 of the National Engineering Handbook.

Getting a dependable water supply cannot be based on the average requirement since the supply would be adequate approximately half the time. It is common practice, therefore, to estimate water needs on a probability basis. High-value crops may justify a water supply that is adequate 9 years in 10. On the other hand for a low-value crop, such as hay or pasture, it may not be economical to provide an adequate supply more than 5 years in 10. Each case must be analyzed individually.

## Quality

Quality is important in evaluating irrigation water supply. Unless water quality has been determined previously, have an analysis made and evaluated before recommending the water for irrigation. Generally impurities carried in solution determine water quality. But those in suspension may have important effects on quality. Whether water of a certain quality is suitable depends on local conditions--climate, soils, crops grown, and depth of water applied.

Rainfall and snowmelt pick up soluble salts and silt particles as they flow along the ground surface to streams. Water flowing in stream channels picks up additional impurities. Runoff water and excess irrigation water that infiltrate into a soil pick up soluble compounds as they percolate through earth formations to streams or to underground reservoirs. Percolating water commonly dissolves more salts than surface water. Unless surface water flows over exposed beds of soluble material, it seldom has a high salt concentration. But stream flows during low-water periods, when discharge is maintained by ground-water runoff, contain higher concentrations of salts than stream flows during high-water periods. Salt concentration in streams flowing through irrigated regions often increases during summer and fall as water moves downstream because of heavily charged return flows of excess irrigation water. In general the proportion of salts in irrigation water is greater (1) in ground-water runoff than in surface runoff, (2) during low stream flow than during high-stream flow, (3) downstream than upstream, and (4) in underground reservoirs than in surface reservoirs.

Stream pollution from industrial wastes and tide and wind conditions affect the quality of irrigation water. Special studies and additional water-analysis data are necessary to evaluate quality fully.

Brackish water is contaminated by acids, basic salts, or organic matter, whereas saline water contains only dissolved salts. Sea water is the chief contaminant of brackish water. Salts may accumulate in soils in humid areas if brackish water is used for irrigation. But because of rainfall and the usually light applications of irrigation water, salt accumulation is usually confined to the upper foot of soil. In areas of high rainfall, winter rains usually leach salts out of the root zone if internal drainage is good.

The amount of brackish water that can be used depends on its salt concentration, number of irrigations between leaching rains, salt tolerance of the crop, and salt content of the soil before irrigation. You should determine the salt content of the irrigation water, check the accumulation of salt in the soil, and know the salt-tolerant crops that can be grown on the area to be irrigated.

Type of Supply

The basic source of water for irrigation is precipitation. Sources of supply are usually considered in two general classes, surface and subsurface. A third miscellaneous class includes city water, sewage, and industrial wastes. The type of supply, particularly its rate of delivery, has some bearing on method of water application and layout of an irrigation system. Various types of water supply are discussed in the following paragraphs. In general water for irrigation is obtained from one primary source, but in some places an additional supply is required from a supplemental source.

Surface Water.--Surface water is a principal source of water for irrigation. Surface supplies include water diverted or pumped from streams; water released from lakes or reservoirs directly into a farm irrigation system or into canals leading to a farm; water pumped from lakes, reservoirs, and canals, or obtained from other surface sources. Excess irrigation water that reaches streams through surface drainage, flow through drainage ditches, or percolating return flow from irrigated land and available for rediversion is generally considered a surface supply.

Streams.--Streamflow is generally the cheapest source of water for irrigation. It is also the least dependable supply. In the East where water rights follow the riparian doctrine, its use is limited to farms abutting the streams. Year-round streams, usually rivers and large creeks, generally are a good source of water. Smaller streams that are dependent almost entirely on rainfall have their lowest flow during the long dry periods when water needs are greatest.

A perennial stream is a dependable source only as long as the acreage to be irrigated needs no more water than the stream produces during drought periods. If the acreage to be irrigated requires more water than the dry-weather flow, the water must be impounded to insure an adequate source. Smaller perennial streams and intermittent streams are not dependable sources unless their water can be impounded.

Unless a stream is large enough that its adequacy as a supply is obvious, it is necessary to determine the dependable dry-weather flow. The U.S. Geological Survey or some other Federal or State agency may have gaged the stream and can furnish data for determining its dependability. If not, it is necessary to measure the flow during a prolonged dry period.

Storage Supplies.--Storage supplies include water held in natural lakes and surface reservoirs. Reservoirs storing water for irrigation range from small impounding or excavated farm ponds to large impounding main-stream reservoirs. Usually large reservoirs are built to furnish water to a group or groups of farmers through some kind of legal organization, such as an irrigation district or conservancy district. Small farm ponds usually are built for use on single farms.

The watershed yield for an impounding irrigation reservoir must be enough to provide the necessary supply during years of low yield. A study of rainfall and runoff records or stream gaging may be necessary to determine this yield. In addition to capacity for storing the gross irrigation-water requirements, allowance must be made for loss of water by evaporation and seepage and capacity loss through siltation (fig. 3-2).

Depth of the water that may be lost through evaporation can be estimated by procedures given in section 4 of the National Engineering Handbook.

Seepage depends on permeability of soil and rock materials at the reservoir site, elevation of the water table in the surrounding formation, hydrostatic head produced by stored water, embankment material, and construction methods. No large reservoir should be constructed without thorough geologic investigation and approval of a competent engineering geologist.

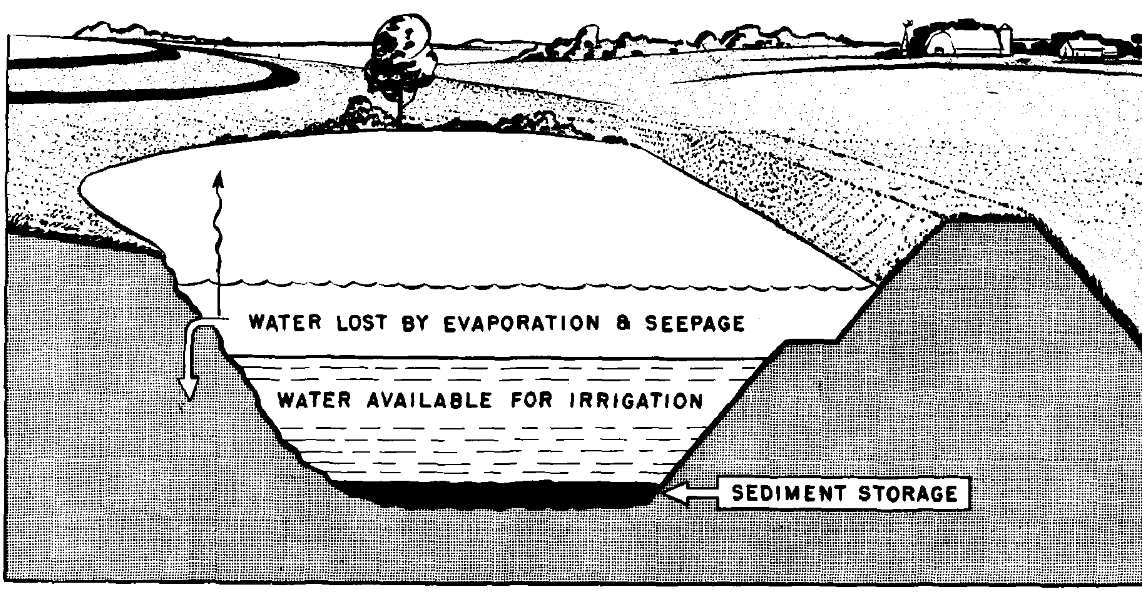


Figure 3-2.--Water loss in an irrigation reservoir.

The capacity required for sediment storage depends on geologic, topographic, and hydrologic conditions throughout the drainage area above a reservoir site. Conservation practices should be established on the watershed before the reservoir is built to hold sediment production to a minimum. Loss of capacity by siltation in small farm reservoirs can often be estimated by studying the effect on similar reservoirs in the immediate area having like topographic and soil conditions. For larger reservoirs or where there are no comparable reservoirs, a detailed study must be made of the likely sediment problem.

Natural lakes are a good source of irrigation water, but often withdrawal of water for irrigation is restricted. More and more of our natural lakes are being developed for recreation and residential use, and everything possible is being done to maintain lake levels. Unless a lake is large or a farmer's land completely surrounds it, or he has legal right to use the water, he may not have a dependable source of irrigation water.

Offstream storage should be considered if streamflow is not enough to provide the required amount of irrigation water or if damming a stream is not possible or feasible. Floodflow in the stream can be diverted through a pipe or open ditch or pumped into an offstream reservoir. The water thus stored can then be used during the low dry-weather streamflow. This method also has the advantage of not interfering with low streamflow, which is important in areas governed by riparian rights. If floodflow is to be impounded, it is necessary to study the floodflow characteristics of a stream to determine if floodflow provides enough water in years of low rainfall or snowmelt. Reservoir capacity should be enough to supply irrigation needs when streamflow is too low to meet them.

At some sites it may be possible to construct an earthen embankment across a gully or small valley that contributes to the stream if the watershed above the embankment is not large enough to furnish the necessary irrigation water. Some runoff can be stored and it is necessary only to pump enough water to fill the reservoir before the irrigation season begins (fig. 3-3).

Supply Canals.--Canals are used to furnish water to groups of irrigators. Water for the canal can come from a reservoir, stream diversion, pumping, or some other source. The supply is controlled by the group or irrigation district. The time and amount of delivery can be continuous, on demand, or at scheduled intervals. Location of the canal with respect to the area to be irrigated and time of delivery of the irrigation water has considerable effect on layout, design, and operation of a farm irrigation system.

Return Flow.--Return flow from an irrigated area is part of the diverted water that finds its way back to a stream channel. It includes surface runoff during irrigation, drainage from canal seepage, leakage at canal structures, waste-water discharge during conveyance, discharge at the

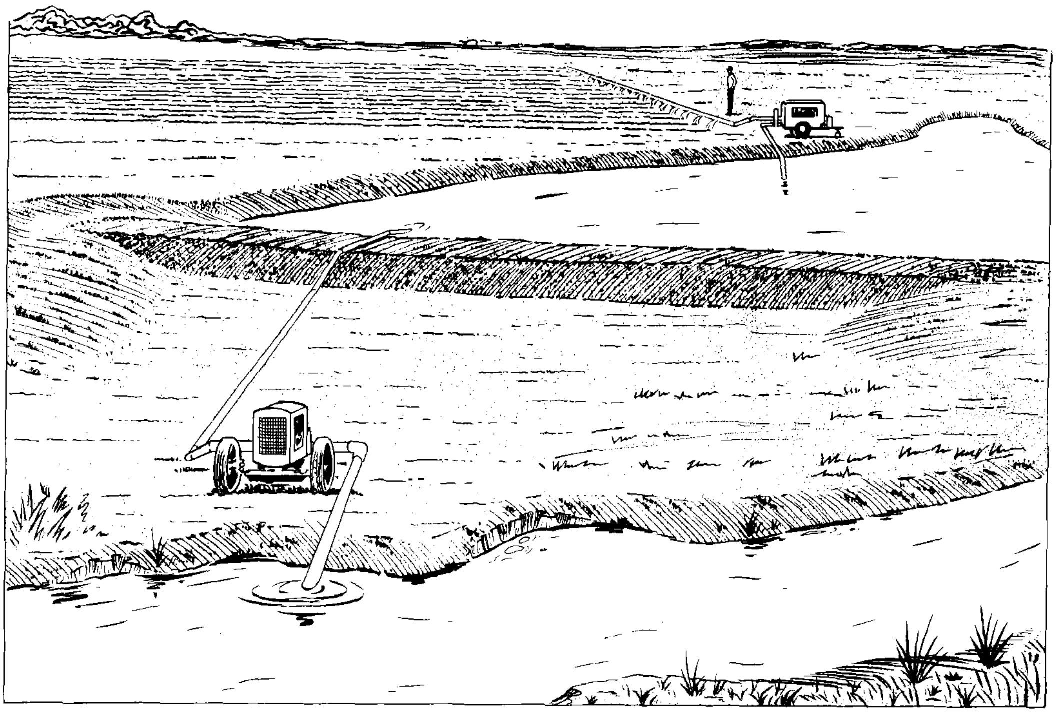

Figure 3-3.--Off-stream storage reservoir.

lower end of the canal, and drainage from excess percolation during irrigation. Return flow can be used to irrigate land below the serviced area or it can be captured for use as supplemental water. The amount of return flow depends on the amount and timing of water diverted, conveyance and irrigation efficiency, subsurface soil formations, surface soil texture, and drainage facilities. It is sometimes possible to impound out-of-season return flow in reservoirs for use during the next irrigation season.

Tail-Water Recovery.--To obtain high efficiency in graded-border or furrow irrigation, it may be necessary to permit some surface runoff at the lower end of a field. In some areas of shallow soils or steep grades, it may not be practical to level land properly. If the water supply is limited, it is often economically feasible to recover this waste water or tail water and pump it back into the delivery system or storage reservoir for reuse, either on the same field or adjacent fields.

The structures required usually consist of a pickup ditch that directs water to a sump or storage basin and a pump and pipelines to deliver water to the desired elevation for reuse. Pickup ditches should be large enough for both irrigation water and runoff from rainfall. Sumps and pumps should have adequate capacity to insure efficient use of the pump-back stream in the irrigation system. If the capacity of the sump or storage pit is low in relation to the volume of runoff that can be expected, automatic controls on the pump are recommended.

Tail-water recovery facilities should not be installed as a substitute for good irrigation water management but as a supplement to increase irrigation efficiency. For furrow irrigation, a tail-water recovery system also can be used to eliminate the labor required for cutback streams while maintaining high efficiency.

Drainage Recovery.--The amount of water that can be recovered by draining an irrigated area depends on soils, losses and waste during conveyance, and excess water delivered to irrigated fields. It is not economical to drain irrigated land for the sole purpose of recovering water. The main purpose of drainage is to reclaim seep areas and prevent further damage to the land. The water recovered may be of lower quality and is generally a supplemental supply that can be used on lower lying land. In some places adequate drainage can be obtained by pumping deep wells near irrigation canals and laterals. The water can be pumped into a canal or lateral to provide an additional supply. For this method to be feasible the underground formation must be porous, extend to considerable depths, and be continuous through a large area so that the water can be drawn from a long distance.

Subsurface Supplies.--Subsurface water is obtained by pumping porous or cavernous formations, using flowing artesian wells, or collecting the flow from large natural springs or seepage areas. Ground water has the advantage of being free from weed seeds and debris, which is particularly important in sprinkler irrigation. Subsurface water supplies are usually developed and operated by individual farmers or by a few landowners working together. The best source of information about availability of ground water is usually a State geologist or a Federal ground-water survey. Local well drillers can also give helpful information.

Wells.--Most irrigation water from subsurface sources comes from wells. An irrigation well consists of a hole, with or without a supporting casing, extending from the ground surface to or into a water-bearing formation. If the well is properly constructed and developed, the maximum amount of water that the water-bearing formation can supply can be pumped. In areas where ground water is plentiful, wells can usually be located near the center of the irrigated area for convenience and economy of pumping.

The requirements for an irrigation well are:

1. The lift should be as small as possible.
2. The well should have a long life.
3. The water pumped must be reasonably free of sand.

Three general kinds of water-bearing formations require pumping plants--sandstone formations, gyp or limestone caverns, and unconsolidated sand and gravel formations.

For sandstone formations, wells are drilled through the water-bearing sandstone, but the casing is set only from the ground surface to the upper limits of the sandstone except in formations that tend to cave. For those wells, the casing extends through the unstable formation.

In limestone and gypsum formations that contain numerous holes or caverns, wells are drilled from the surface through the limestone or gypsum into the cavern, and the casing is set from the surface down to and bedded in the rock.

In unconsolidated sands or gravels, wells are drilled through the water-bearing formation, and the casing is set the entire depth of the well. The lower end of the casing consists of either a perforated section or a well screen that permits water to pass from the water-bearing sands or gravels into the well.

A group of wells drilled in one of these formations has certain general group characteristics, but each well must be individually analyzed, designed, and constructed. No two water-bearing formations are exactly alike, and no well should be drilled and developed exactly like a nearby well without first determining the best development procedures.

Wells are dug, driven, or drilled depending on the depth to which they must go, nature of the materials through which they must pass, rate at which water is to be removed, and elevation of the ground-water table.

Dug or open-pit wells are usually excavated by hand into the water-bearing strata. Before modern well-drilling equipment was available, most wells were dug. They are most practical for (1) developing shallow thin water-bearing strata that require large-diameter wells and (2) installing a pumping unit close to the ground-water table.

Driven wells are constructed by forcing a pipe into the ground until it penetrates the water-bearing strata. They are limited to depths of less than 50 feet in soft material.

If the water-bearing materials are near the surface but are not deep enough to supply enough water through a single well, a battery of sand-point wells can be connected to a pumping unit by a manifold. In planning a well-point system it is important to space individual wells so that their areas of influence overlap only slightly or not at all. Although it is seldom practical to calculate the size and shape of the areas of influence because of the cost of making the tests needed to measure the drawdown curve, some general rules based on judgment and experience can be followed in spacing the wells.

A spacing of 25 to 50 feet between sand points generally has worked nicely. Wells can be closer together in fine sand formations and where the aquifer is thin. They can be farther apart if the aquifer is deep enough and thick enough to permit installing long well screens (10 feet or more) in the wells.

Drilled wells are put down by percussion drills or rotary drills or some modification of these tools. They can be drilled to any desired diameter to about 36 inches, through almost any material, and to any practical depth. For these reasons drilled wells are the most common irrigation wells. A casing is installed in the drilled hole down to the water-bearing strata and a well screen is attached to the bottom of the casing. If the aquifer is predominantly sand, a perforated casing with a graded gravel pack is generally used instead of a well screen.

Artesian Water Supplies.--Water from flowing artesian wells or pumped from artesian aquifers can be used for irrigation. Substantial amounts of water can be obtained from artesian aquifers that underlie large areas and carry water under relatively high pressure. Annual withdrawal should not exceed annual recharge continuously. Otherwise artesian pressure decreases, flowing wells soon cease to discharge, and pumping is necessary. Eventually the supply of water is not adequate for proper irrigation.

Springs.--Natural springs near the land to be irrigated can be used as a water source for irrigation water if they discharge appreciable flows during the irrigation season. Usually the discharge is not enough to provide an adequate irrigation stream, and some kind of storage basin is required. If there is a series of springs in a given area, it may be possible to collect the discharge into one channel. A perched or contact spring is usually the least dependable because of the limited flow available. An artesian spring usually is the most dependable. Dependability of springs is difficult to estimate because of the many variables that affect the source of supply. The kind of spring, conditions found during exploratory excavation, and local information on past behavior of the spring are all factors that must be considered. The capacity of springs can often be improved by excavating, cleaning, capping, or providing collection and storage facilities. Sound judgment must be used to avoid expensive development of springs that may soon go dry.

Seepage.--Underground seepage water can be intercepted and stored in excavated reservoirs in some localities and used for irrigating small areas (fig. 3-4). Reservoirs usually are excavated in low-lying level areas where lateral movement of water underground replenishes the supply. Dependability as a source requires a high natural water table under adjacent land and a highly permeable layer that permits rapid lateral movement of water within a practical excavating depth, usually 12 to 20 feet. The success of these reservoirs depends on the rate of recharge because most of them are small. The most successful reservoir is one large enough to provide a full day's irrigation from storage and inflow and is refilled by seepage during the night. In some places additional water can be captured from springs, tile lines, or surface runoff.

Regulating Storage Reservoirs.--If economically attainable flow is too small for irrigating directly from a well or spring, regulating reservoirs can be used to advantage (fig. 3-5). Continuous small flow can be stored in a regulating reservoir, thus providing enough flow at a rate

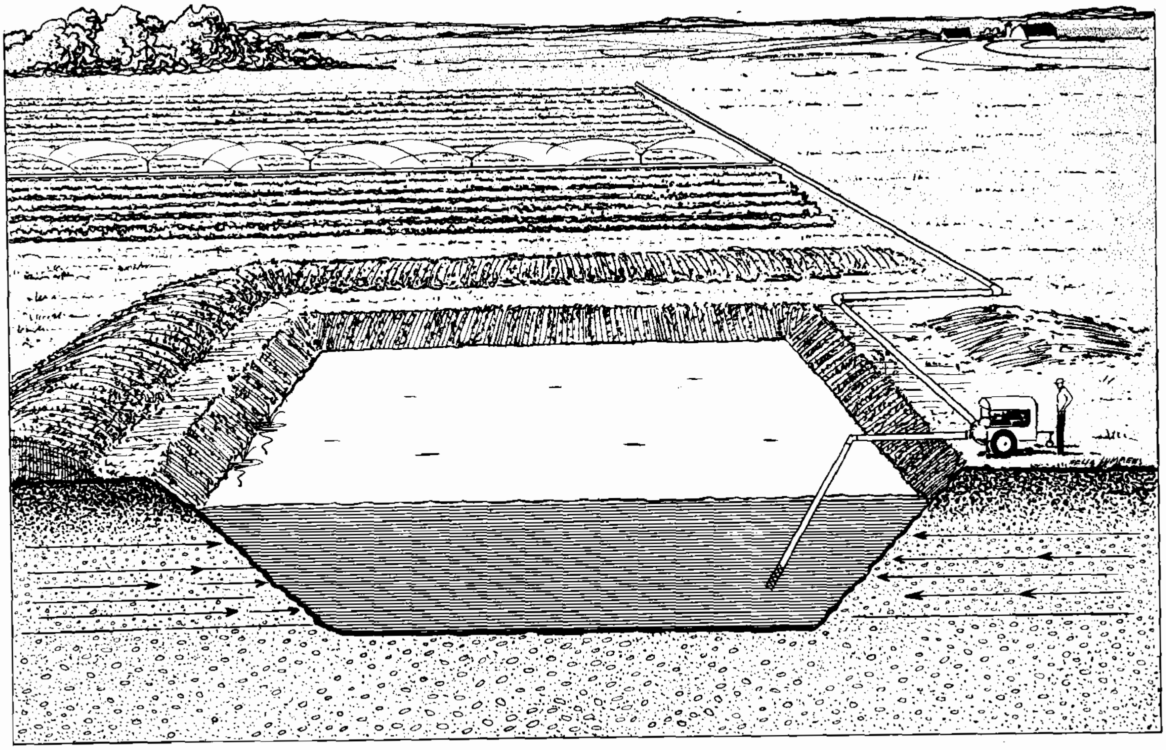

Figure 3-4.--Ground-water storage reservoir.

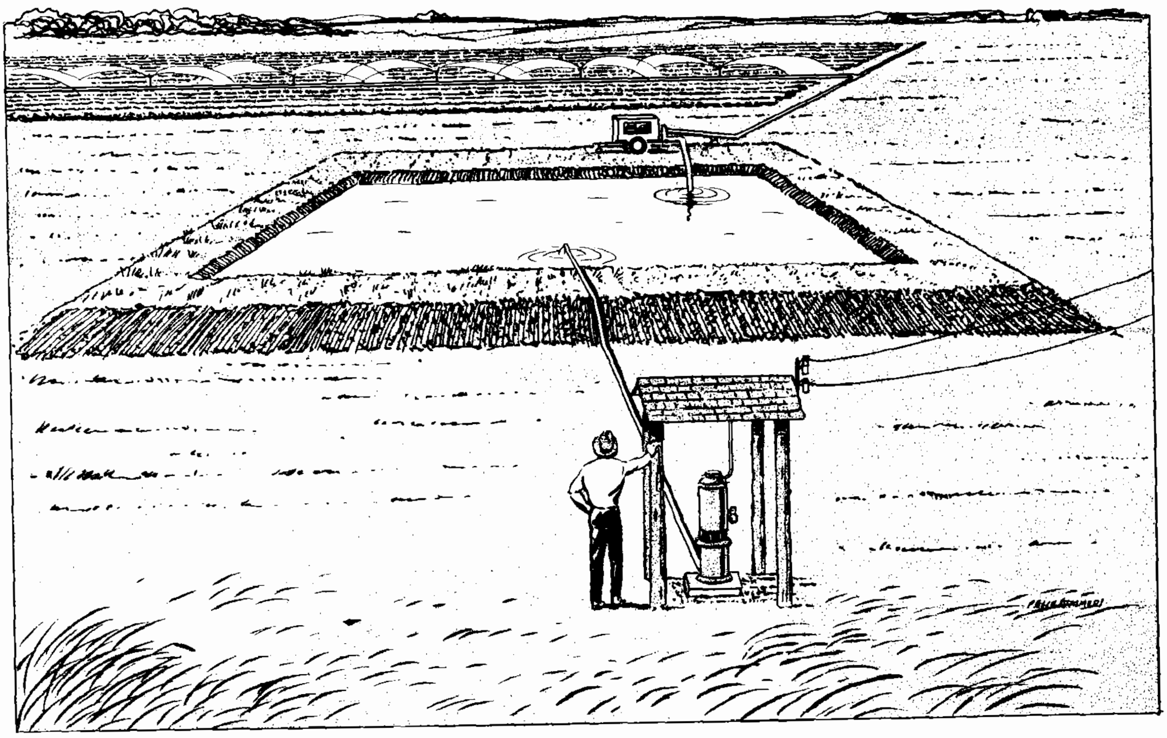

Figure 3-5.--Regulating reservoir.

to operate the required size of irrigation system to make an irrigation application. In other words, flow into the reservoir is continuous but the irrigation equipment is operated intermittently. The timing depends on size of the irrigation system, storage capacity of the reservoir, and inflow rate.

Regulating reservoirs are built either by excavating a pit and using the spoil material to build a levee around it or by building an earthen dam across a low area. Size is generally determined by the amount of water needed for one day's operation. The reservoir should be large enough to store all inflow while the irrigation system is not in operation. For example, if the source of water is a small well pumping 24 hours a day at 200 gallons per minute and the irrigation system uses 400 gallons per minute, the system can be operated 12 hours a day if the reservoir is large enough to store water for 12 hours of pumping. The rate of discharge should be determined for the period of lowest flow so that enough water can be stored for low-flow periods. A regulating reservoir can also be used to store continuous small deliveries from canals and laterals. Often it is called an overnight-storage reservoir.

Miscellaneous Sources.--Minor sources of water are city water, effluent from sewage-treatment plants, and waste water from industrial plants. The quantity of water available from these sources is usually small and only enough for irrigating small areas near the point of disposal.

City Water.--City water can be used for irrigating suburban land. Water from city mains, although usually too expensive and inaccessible for general farm use, has been used on some small areas of high-value crops near towns. Although water costs are high compared to those for other supplies, for small systems water pressure in the city mains is enough for irrigating small areas without using booster pumps, thus avoiding pumping costs. Size of the main and water pressure affects rate of delivery and consequently design of the irrigation system.

Sewage Water.--Effluent from sewage-treatment plants can be used for irrigating nearby small areas. Sewage discharge is return flow from domestic and industrial uses. Since it often amounts to two-thirds or more of the water delivered to consumers, sewage flow from large cities can be an important source of water for irrigation.

In considering the use of sewage effluent for irrigation, the possibility of contaminating crops and polluting ground water must be investigated. Many States have regulations governing the use of sewage effluent for irrigation. Check the State regulations before doing any irrigation planning that considers using sewage effluent as the water supply. Sewage effluent is more suitable for use on coarse-textured sandy soils than on fine-textured silt and clay soils. The fine sediments in sewage flows may improve the structure of sandy soils. Deposition of these sediments on the soil surface can decrease the permeability of silt and clay soils.

Industrial Waste Water.--Waste water from food processing and canning plants can be used for irrigation if there is a supplemental supply that can be used during the part of the season the plant is not in operation. Continuous flow from other kinds of industrial plants may be a good source of water if it does not contain harmful chemicals and sediments. In any case the water should be analyzed to determine if its use will have harmful effects on the crop or soils. Most of this waste water carries sediments in suspension that may affect the type and design of an irrigation system.

Location of Supply

Location of the water supply has considerable effect on the layout, design, and operation of an irrigation system. In many places location is fixed by conditions beyond your control as a planner. You must then fit the irrigation system as best you can to the fixed location. If there is a choice, locate the supply at the point that will give the lowest estimated cost of delivery to each part of the irrigation system. Consider the following general points.

1. Accessibility for operation and service
2. Length of delivery facilities to each field in the system
3. Erosion protection for supply ditches
4. Possible use of gravity flow from the point of supply
5. Location of temporary storage reservoirs if needed

The location of natural lakes is fixed and there is generally little opportunity for choice in the location of impounding or excavated reserviors. If the water supply is to be pumped for surface irrigation, it is usually located at the highest point in the field or near the highest point, which may or may not be the best location. Often it is desirable to locate the supply somewhat below the highest point of the field and to carry the required amount of water necessary to irrigate the higher area to the top of the slope in a pipeline. This is the best plan if the high area is a knoll constituting only a small part of the field and the remainder of the irrigated area is several feet lower. If the source is a well at the high point of the field, all the water for irrigating the entire field must be pumped to this elevation. It is then carried back down the slope to the point of use in a pipe or through a series of ditch checks that control velocity. Since pumping cost is directly proportional to pumping lift, it increases in proportion to any added lift. If the source is a group or district canal, its location is generally fixed at or near the high point of the area to be irrigated and there is little choice in location of the point of takeout.

Wells generally offer the most flexibility in location. In some places location is fixed because of availability of an adequate aquifer. If the aquifer is extensive, the well generally can be located at the most advantageous point.

If a sprinkler system is planned, usually the well should be near the center of the land to be irrigated. The saving obtained through proper location can amount to several hundred dollars through the smaller pipe and shorter main line that can be used. For surface irrigation using either surface or underground pipe, the well should be located where the shortest and smallest (diameter) pipeline can be used to service the area to be irrigated. This location depends on topography of the field and design of the water-application system.

Wells are often located close to a farmstead merely for convenience in servicing. In addition to any extra pumping costs caused by this location and the cost of extra pipe and ditches, the well often interferes with or may even dry up domestic wells on the farmstead. Convenience in servicing well pumps and motors is important in chosing the location. Access lanes from the farmstead to the well should always be provided.

Generally, there is little choice in location of the takeout if irrigating from natural streams. If the stream flows through the area to be irrigated, it may be possible to adjust the point of takeout to fit in with the overall layout of the farm irrigation system. It may be advantageous to consider more than one takeout from the stream. Topography and stream location are the major factors to consider in selecting the point of takeout.

### Climate

Climate is a factor affecting irrigation for an entire area. For irrigation its classification--humid, semiarid, and arid--generally is based on precipitation. Humid regions receive more than 30 inches of precipitation, semiarid 15 to 30 inches, and arid less than 15 inches. Climate directly affects the growth habits and requirements of plants (chap. 1). Therefore a conservation irrigation system must be designed so that it works in the existing climatic conditions.

### Precipitation

Annual precipitation determines the amount of water available for irrigation storage. Rainfall during the growing season, particularly its distribution, affects the amount and frequency of irrigation needed. Land receiving an appreciable amount of rainfall during the growing season may need only a small amount of irrigation water, depending upon rainfall distribution. In some years of adequate rainfall well distributed, irrigation may not be needed at all. Land that receives enough rain in the spring to fill the root zone may not require irrigation until the crops have attained considerable growth. Land that receives only small amounts of rain during the spring and summer months requires the most irrigation water, and the irrigation system must be designed to supply the full amount of water needed for good crop production.

Excessive precipitation or high-intensity rainfall produces runoff that may result in erosion and make drainage necessary. Irrigation planning must take into consideration drainage and erosion control measures.

Temperature

Temperature directly affects water requirements for crop production and the design of an irrigation system. Growth of most plants is slowed or arrested at low temperatures. Since evaporation and transpiration are rapid at high temperatures, soil moisture is soon depleted.

Length of the growing season and temperatures during the growing season determine the kinds of crops that can be grown profitably. It is possible to lengthen the growing season for some crops by irrigating. Strawberries have been protected successfully against late-spring frosts. Cranberries and low-growing vegetable crops, such as tomatoes, cucumbers, peppers, beans, and squash, have been provided time to mature near the end of the season by irrigating. Chapter 11 of section 15 outlines design information on sprinkler irrigation for frost protection.

Irrigation can be used to control high daytime temperatures that otherwise reduce the quantity and quality of fruit. Sprinkler irrigation during the heat of the day can reduce field temperatures around a plant as much as $15^{\circ}$ to $20^{\circ}$ F. and increase humidity by 15 to 25 percent. The sprinklers must be designed to apply as near a fine mist as possible over the entire field (as in a frost-control system). They are turned on when high temperatures that seriously affect a plant are reached and are operated until the temperature has dropped below the danger stage.

Inclusion of frost protection or temperature control in an irrigation system affects the selection of application method as well as the planning, design, layout, and operation of the system.

Farm Enterprise

Before planning a farm irrigation system, you must know the type of farm enterprise--livestock, cash crops, or a combination--as well as the farm operation schedule planned and the labor available for irrigating. All these factors influence the choice of water-application method, layout and operation of the irrigation system, and intensity of irrigation. The kind of crops to be grown and available labor are the most important items to consider.

Crops

Some crops need more water for high yields than others. Some use more water (peak use) during the early part of the growing season and others, later in the season. Crops that mature during the early part of the growing season generally have a lower peak-period use rate than those maturing in the latter part. The moisture-extraction pattern of shallow-rooted and deep-rooted crops varies considerably, which affects the amount of water to be applied at each irrigation and frequency of irrigation (chap. 1).

Know the acreage and field boundaries for each kind of crop and the rotation planned. Consider the cover and soil-improving crops to be grown in the rotation as well as the row crops. Any irrigation system designed for a field must meet the requirements for conservation irrigation of all the crops to be grown. The kind of crop to be grown usually determines the choice of water-application method.

Labor

Irrigation usually requires extra farm labor. The amount depends on the type of system, water-application method, and labor-saving devices installed with the system. Even for nearly automatic systems, it is necessary to have someone watch the operation closely if high efficiency is to be attained. Get a clear picture of farm schedules to know how much time can be devoted each day to irrigation without neglecting other work. From this information you will know if full-time irrigators are needed during the growing season or if regular farm labor can be used at different times of the day or night. Plan the irrigation system with the farmer's labor supply in mind. If he has plenty of labor, it is generally possible to provide a system of lower initial cost because labor-saving devices are not needed. If he does not have much help, various degrees of automation can be built into the system but this increases the initial cost over that for a hand-operated system.

Field Arrangement

Having fields of workable size and shape is important to successful irrigation farming. Often both size and shape must be changed to provide an efficient irrigation system. Unless a system is carefully planned, some areas may not receive irrigation water or some small areas may be virtually inaccessible or useless to the farm enterprise. Sharp turns or acute farming angles difficult or impossible to farm with modern farm equipment must be avoided. To have fields that can be farmed economically and irrigated with one or more uniform sets, use the following criteria for size and shape.

1. Base length on the maximum allowable run for the method selected. It can be in even multiples of the proper design length.
2. Base width on the cropping system, operations schedule, and type of equipment.
3. Base field divisions on ownership boundaries, obstructions, soil boundaries, land slopes, and land use or cropping system.
4. Plan fields as nearly rectangular in shape as possible.
   a. Plan length of run to be uniform to permit a workable operating schedule.
   b. Avoid sharp turns or block corners.
5. Remember the importance of good accessibility.

Farm Equipment Available

A farmer's present equipment for planting, tillage, and harvesting may have some bearing on selection of irrigation method and layout of the system. It may be better and more economical for some irrigators to get different farm equipment to have a better and more efficient irrigation system. The question of farm equipment should be settled before the final planning so that the system installed is compatible with the farm equipment to be used.

Available Power

Determine and compare the sources of power available for operating the irrigation system. If electricity, note the location of the nearest transformer and other features, such as phase, voltage, and horsepower limitations. Pay particular attention to power rates and standby charges.

Existing Facilities

It is particularly important in planning the rehabilitation of an irrigation system to find ways of using the present facilities before considering any changes in method or system layout that necessitate abandoning or relocating permanent structures. If possible, make some use of any equipment already on a farm if it is in good condition. But under no circumstances should you plan for a less efficient irrigation method not suited to the site merely to use such facilities.

Field Road System

The need for a field road system is often overlooked in planning with the result that some of the farm is inaccessible to farm machinery, the irrigation system is damaged by travel of farm machinery, or the roads are impassable after an irrigation. Provide roads above irrigation ditches and below field drains that are readily accessible for working the farm. Consider the following points in planning a farm road system.

1. Ease of operating the water-distribution system
2. Ready access to all areas of the farm for farm equipment
3. Transportation of farm produce from the fields
4. Dryness and usability of roads

Finances

Financing an irrigation system is the farmer's responsibility. But tell him the probable cost of the system selected before doing any detailed planning. He may not realize the cost involved and may find that he cannot finance the proposed plan. If so, plan to irrigate a smaller acreage at first, increasing the acreage as finances permit. Be certain that the initial development will fit in with the complete irrigation plan for the farm without costly alterations.

Physical Features

Permanent surface features, such as power lines, pipelines, conservation measures, etc., must be considered. Since power lines generally are expensive to move, plan to build the system around them. Determine location and depth of pipelines or buried cables. Often they are limiting factors in land leveling or ditch building. If they are relatively shallow, they may be damaged or destroyed during construction. Maintenance of pipelines often damages an irrigation system by blocking borders or disrupting benches.

Windbreaks, orchards, fences, farmsteads, diversions, terraces, and similar obstructions greatly influence the layout. Usually fences can be changed, but other obstructions generally are fixed and the system must be built around them. If you do not allow for these features in planning, you may start the layout only to find that part of a field is so isolated it cannot be fitted into the irrigation system. This is especially true when irrigation systems are planned and installed on a piecemeal basis.

## Adapted Methods of Water Application

Irrigation water application is commonly designated according to the manner in which water is applied to the soil. The three basic ways of applying irrigation water are

1. Sprinkler irrigation--the soil surface is wetted much as it is by rainfall.
2. Surface irrigation--water is applied by complete flooding or in furrows, wetting only part of the surface.
3. Subirrigation--water is applied beneath the surface, wetting the surface little if at all.

Methods of applying irrigation water vary with topography, soil conditions, amount of land preparation practical, crops to be grown, value of crops, cultural practices, and available water supply. Each method has certain limitations. Most can be adapted to a fairly wide range of conditions. On some sites several methods of water application are suitable. On other sites only one method can be used. In some areas farmers have become accustomed to particular methods of applying water and continue to use them even though others are more desirable and economical. Sound planning must also consider for each suitable method the cost and ease of installation, maintenance required, cost, labor and skill required for operation, and ease with which it can be fitted into the farm enterprise. To get acceptable irrigation efficiency, skill of the operator and flexibility of the system must be considered along with the irrigator's wishes in selecting the best method.

### Sprinkler Irrigation

Water is sprayed into the air through a sprinkler nozzle and allowed to fall on the land surface in a uniform pattern at a rate less than the intake rate of the soil.

Sprinkler Method

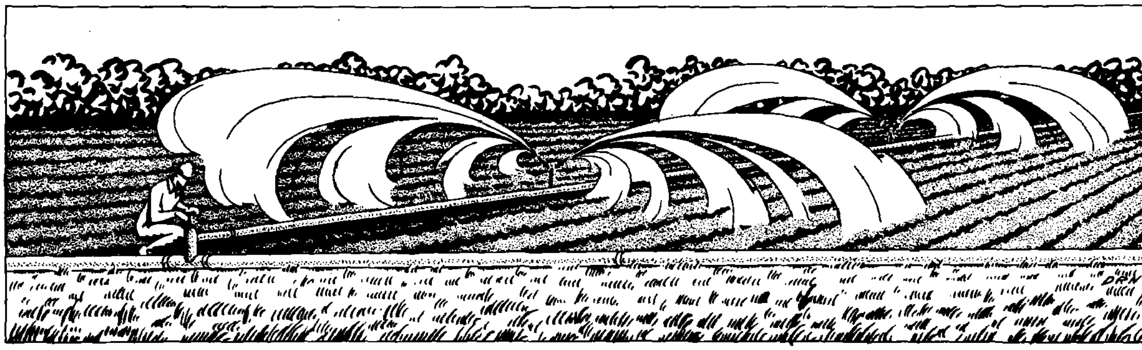

Figure 3-6.--Sprinkler irrigation.

Description.--Irrigation water is pumped from the source through pipes to the sprinklers and sprayed into the air (fig. 3-6). Two types of sprinkler systems are used to irrigate farm crops. In one, rotating sprinkler heads are spaced equally along the lateral lines. In the other, the lateral lines are perforated pipe. The lateral lines remain in one place until the required amount of water has been applied and are then moved the same distance for each successive setting. Perforated-pipe sprinklers deliver water through very small, closely spaced orifices in the pipe, provided fairly uniform distribution along both sides of the pipe.

Sprinkler systems can be semipermanent, having fixed main lines and portable laterals, or be fully portable in which both mains and laterals can be moved. In a solid-set system the entire field is served simultaneously by laterals lines. The main and laterals can be either located on the ground surface or buried for a totally permanent system.

Different kinds of sprinklers are shown in figures 3-7 to 3-14. Design criteria for sprinkler irrigation systems are discussed in chapter 11.

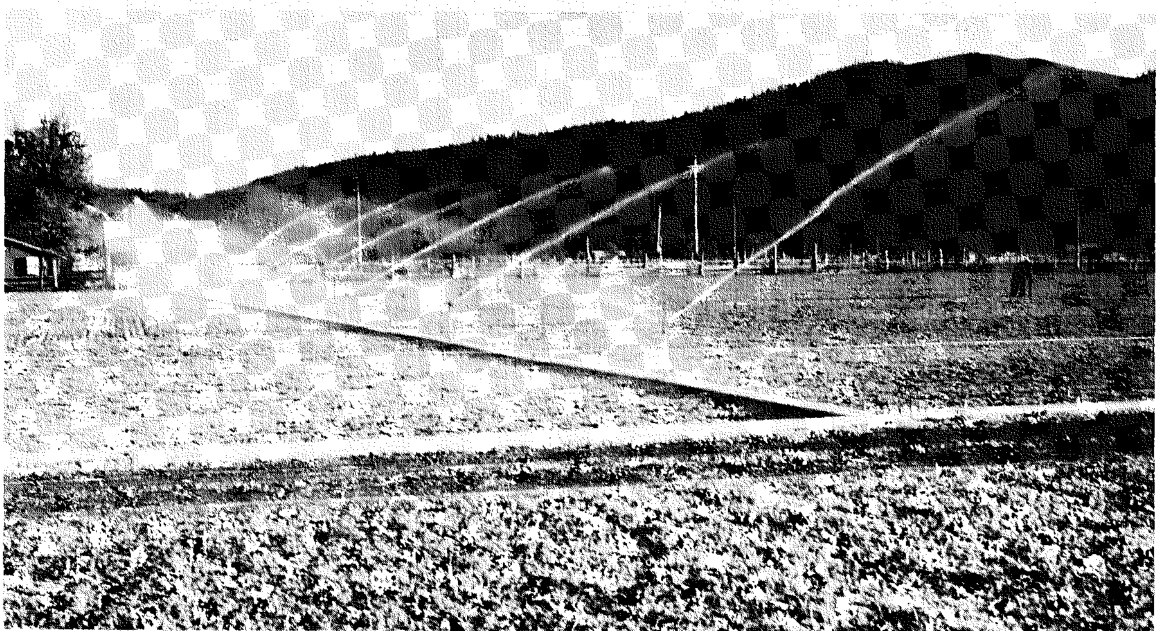

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Figure 3-7.--Hand-move sprinkler.

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Figure 3-8.--Big-gun sprinkler.

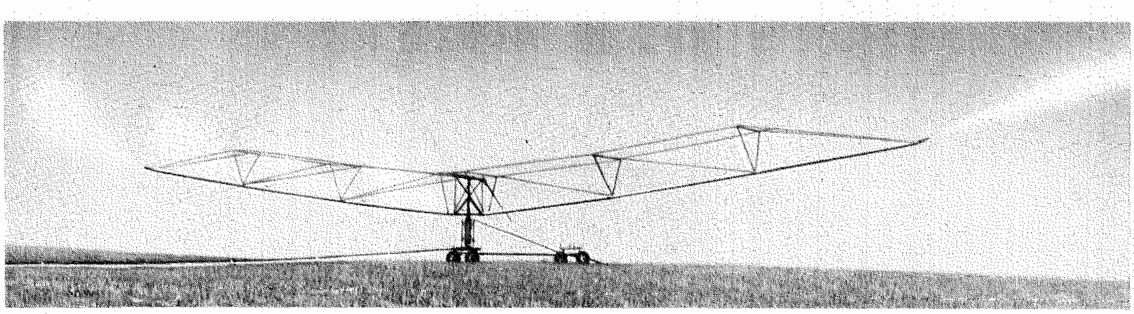

Figure 3-9.--Rotating-boom sprinkler.

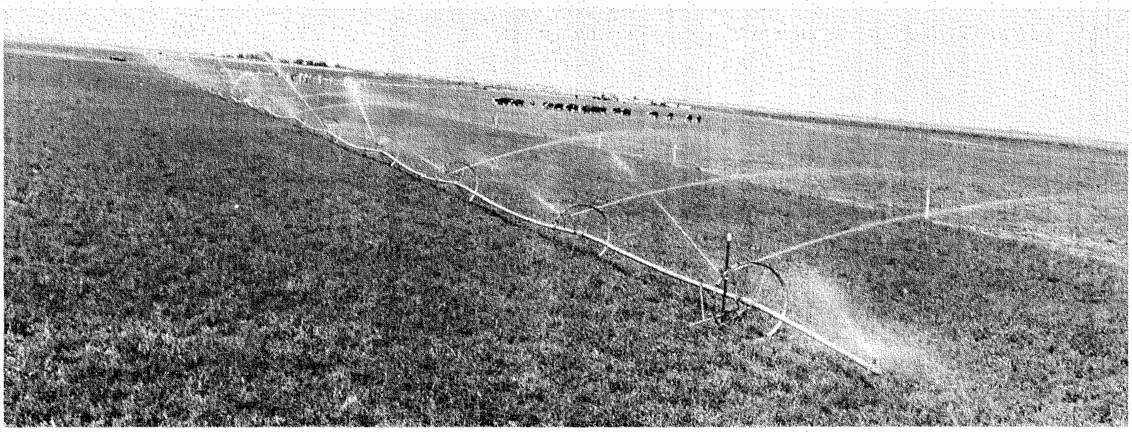

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Figure 3-10.--Side-roll sprinkler.

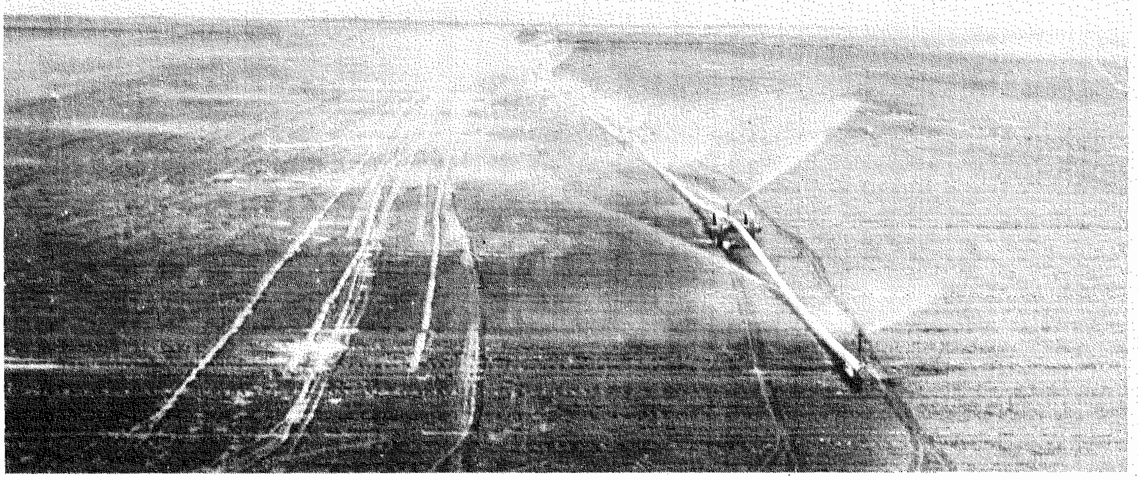

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Figure 3-11.--Two-lateral sprinkler.

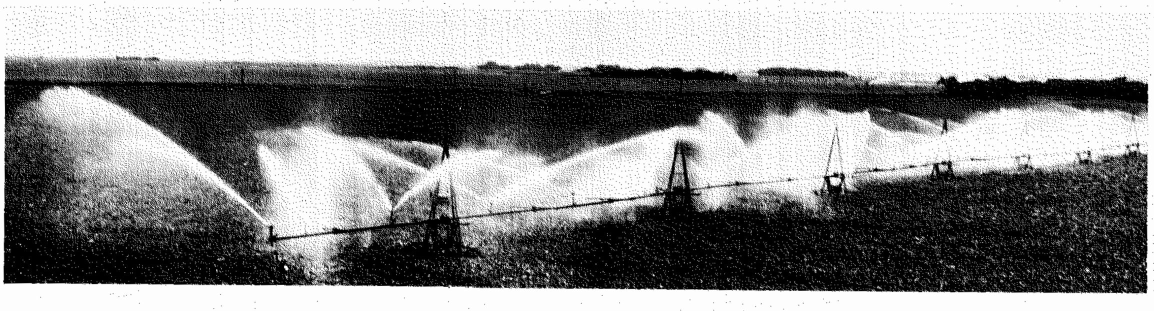
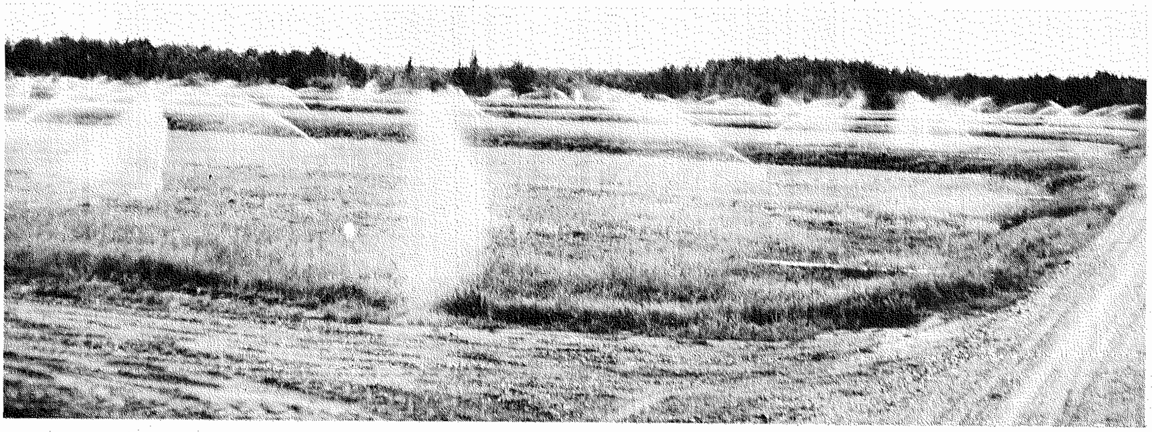


Figure 3-12.--Self-propelled sprinkler.



NEB-2142

Figure 3-13.--Solid-set sprinkler.

TEX-42802

Figure 3-14.--Perforated-pipe sprinkler.

Adaptability.--All crops except rice can be sprinkler irrigated. Sprinkler irrigation is suited to all soils having an intake rate higher than the rate of application. It is particularly suited to sandy soils that have a high intake rate. Soils too shallow to be leveled properly for other methods can be irrigated safely by sprinklers. Sprinkler irrigation can be used on any topography suitable for farming. It is especially suitable for steep slopes or irregular topography without extensive land preparation and for soils that cannot be leveled. If soil erosion is a hazard, sprinkler irrigation can be used in conjunction with mulching, terracing, and strip cropping.

Important Features.--Land leveling is not required. Some smoothing or grading is advisable if surface drainage is a problem or to provide a more uniform surface for seeding, tillage, and harvesting. Land too steep for efficient use of other methods can be irrigated safely. The cost of land leveling can be eliminated or greatly reduced. Small streams of irrigation water can be used efficiently, and well-designed sprinklers distribute water better than other methods. Surface runoff of irrigation water can be eliminated. The amount of water can be controlled to meet crop needs, and light applications can be made efficiently on seedlings and young plants.

Soluble fertilizers, herbicides, and fungicides can be applied in the irrigation water economically and with little extra equipment. Penetration of fertilizers into the soil can be controlled by applying the fertilizer at selected times during the application of water. Sprinkler irrigation can be used to protect crops against frost and against high temperatures that reduce the quantity and quality of harvest. It is the most efficient method for such protection. It may be necessary to add lateral lines and sprinklers for adequate temperature control.

Labor costs are usually less than for surface methods on soils having a high intake rate and on steep and rolling land. Sprinkler irrigation systems can be moved once or twice a day as a regularly scheduled part of the farm operation.

Limitations.--Wind distorts sprinkler patterns and causes uneven distribution of water. Ripening soft fruit must be protected from the spray. A stable water supply is needed for the most economical use of the equipment. The water must be clean and free of sand, debris, and large amounts of dissolved salts. Unburied mains and laterals may interfere with cultivation, spraying, and other farm operations.

The sprinkler method usually requires the highest initial investment of any method except where extensive land leveling is necessary for surface or subsurface irrigation. More special equipment subject to depreciation is needed. Power requirements are usually high since sprinklers operate with a water pressure of 15 to more than 100 pounds per square inch. Fine-textured soils that have a slow intake rate cannot be irrigated efficiently in hot windy areas. If water is applied at the low rate required for these soils, the percentage lost by evaporation and wind drift increases. Cost of labor or equipment may be higher on fields that remain muddy for some time after an irrigation.

## Surface Irrigation

Water is applied directly to the soil surface either by controlled flooding or in some kind of furrow. In controlled flooding the water applied to the surface is controlled by dikes and ditches. Graded-border, level-border, contour-levee, and contour-ditch methods are different types of controlled-flooding irrigation. In the furrow method, water is applied through regularly spaced large furrows, furrows between crop rows, or closely spaced small furrows or corrugations. In general, flooding methods are used for close-growing crops and furrow methods for row crops.

### Graded-Border Method

Description.--Graded-border irrigation is a form of controlled surface flooding. The field to be irrigated is divided into strips by parallel dikes or border ridges (fig. 3-15), and each strip is irrigated independently. The border strips should have little or no cross slope but should have some slope in the direction of irrigation. Each strip is irrigated by turning in a stream of water at the upper end. The stream must be large enough to spread over the entire width between the border ridges without overtopping them. Usually the stream size should be such that the desired volume of water is applied to the strip in a time equal to or slightly less than that needed for the soil to absorb the net amount required.

Adaptability.--This method is suitable for irrigating all close-growing, noncultivated, sown or drilled crops, except rice and any other crops grown in ponded water. Legumes, grasses, small grains, and mint commonly are irrigated by this method. Graded borders also are used for irrigating orchards and vineyards.

Graded-border irrigation can be used on most soils. It is best suited to soils that have a moderately low to moderately high intake rate. Usually it is not used for coarse sandy soils that have a very high intake rate because of the stringent limitations on design. Nor is it well

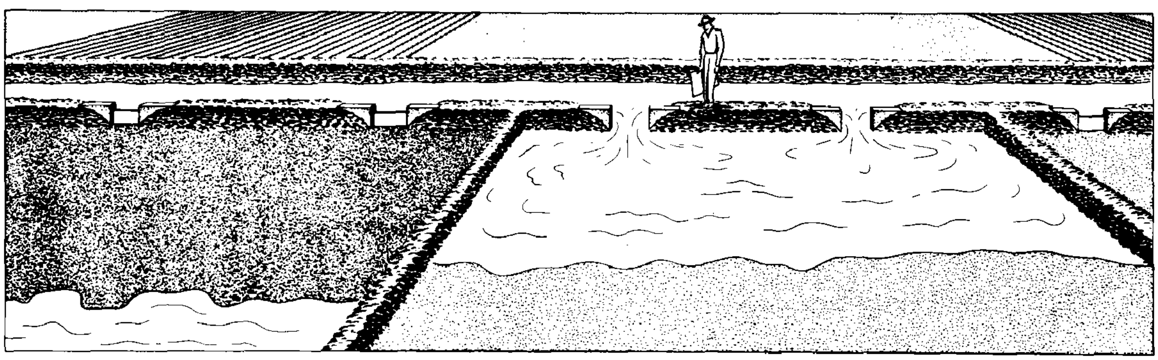


Figure 3-15.--Graded-border irrigation.

suited to soils having a very low intake rate since, to provide adequate intake time without excessive surface runoff, the irrigating stream may be too small to completely cover the border strips. This method is best suited to slopes of less than 0.5 percent. If erosion from rainfall is not a hazard, it can be used successfully on steeper slopes if the soil intake rate is not too low. For nonsodforming crops, this method is seldom used on slopes of more than 2 percent, but it can be used on slopes as steep as 4 percent for sod crops. In humid areas the maximum slope to be irrigated by this method is about 2 percent for sodforming grasses and 0.5 percent for other crops.

Important Features.--Good to excellent field application efficiency can be obtained if the borders are well designed and installed. Labor requirements are among the lowest for all application methods, and strip width can be designed to accommodate the farm machinery used for tillage, planting, and harvesting. If surface drainage is critical, the method is an excellent means for rapid disposal of excess surface water.

Limitations.--Topography must be relatively smooth or soils deep enough for adequate leveling. In some areas, land-leveling costs may be high enough to exclude using the graded-border method. The available irrigation stream must be large enough to irrigate a border strip of practical size. Young crops may be damaged or extra tillage required on soils that bake or crust after wetting. A light irrigation of less than about 2 inches is difficult to apply efficiently.

Level-Border (Basin) Method

Description.--This method is based on the rapid application of irrigation water to a level or nearly level area enclosed by dikes that retain the water at a uniform depth until it has been taken into the soil (fig. 3-16). Level borders are similar to basins, but basins generally are as wide as they are long and level borders are several times longer than wide.

An overall fall of 0.2 foot in the length of the border strip is often desirable as construction tolerance to avoid reverse grades. The stream of water turned into each border should be at least twice that required for the average intake rate of the soil. If the border is level, the

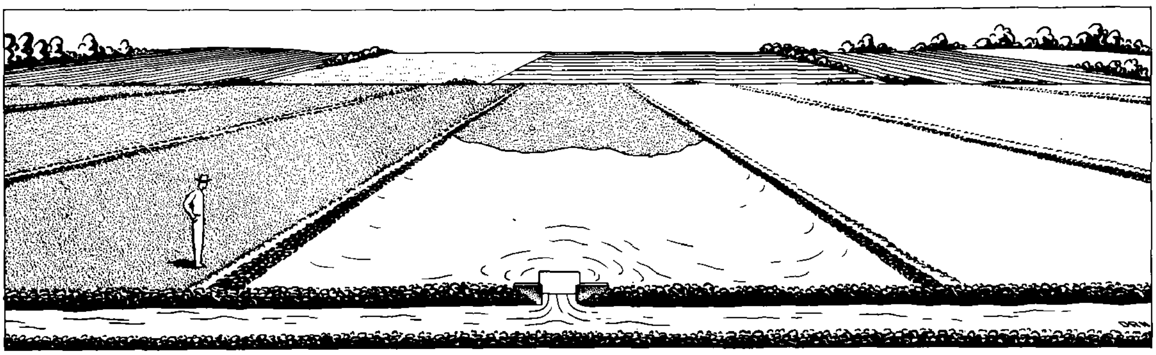


Figure 3-16.--Level-border irrigation.

irrigation stream can be turned in at any point or points around the border and at both ends if desired. If the border has a slight grade, the irrigation stream is applied at the upper end.

Adaptability.--This method is best suited to soils having a moderate to slow intake rate (2.0 intake family or less) and a moderate to high available water holding capacity. Although an efficient system for water application can be designed for soils that have a higher intake rate and a lower available water holding capacity, the borders are so small that they interfere with cultural practices and the location of delivery laterals.

Smooth, gentle, uniform land slopes are best suited to this method and give the best field layouts. One major advantage of this method is that it can be used to irrigate many different kinds of crops regardless of planting pattern. Crops such as carrots, which are adversely affected by flooding, can be planted in beds and irrigated with light applications in the intervening furrows. Row crops less susceptible to flooding can be flat-planted or bedded. Sown crops, drilled crops, and sod crops can be irrigated by using border furrows to guide the water. These wide variations can be accomplished without basic changes in layout or rate of application and still give high efficiency.

Important Features.--Many different kinds of crops can be grown in sequence without making major changes in design, layout, or operating procedures. Leaching can be accomplished without changing either layout or method of operation. Provisions for disposal or reuse of tail water are not needed although removal of excess rainfall may be necessary. Maximum use can be made of rainfall. No irrigation water is lost by runoff. This method can be adapted to automation easily or it can be operated efficiently by inexperienced labor. High application efficiency can be obtained.

Limitations.--Accurate land leveling is generally required. Border dikes must be high enough to keep the irrigation stream from overtopping the ridges. Border ridges may interfere with movement of farm machinery in border strips. On steep slopes requiring benching, drop structures, lined ditches, or pipelines may be required for adequate water control. In some areas special provisions must be made for surface drainage. In areas where wind velocity exceeds 15 to 20 miles per hour, it may be difficult to apply irrigation water if the wind direction is opposite to the direction of water flow in the border strip. Sets must be changed often. Maintenance of a level surface is essential to efficient operation, which may require changing tillage operations or using special tools, or both.

### Contour-Levee Method

Description.--This method is a modification of the contour-border or basin method. Areas bounded by small contour levees and cross levees are completely flooded (fig. 3-17). Water applied at a rate considerably in excess of the intake rate of the soil spreads rapidly over the

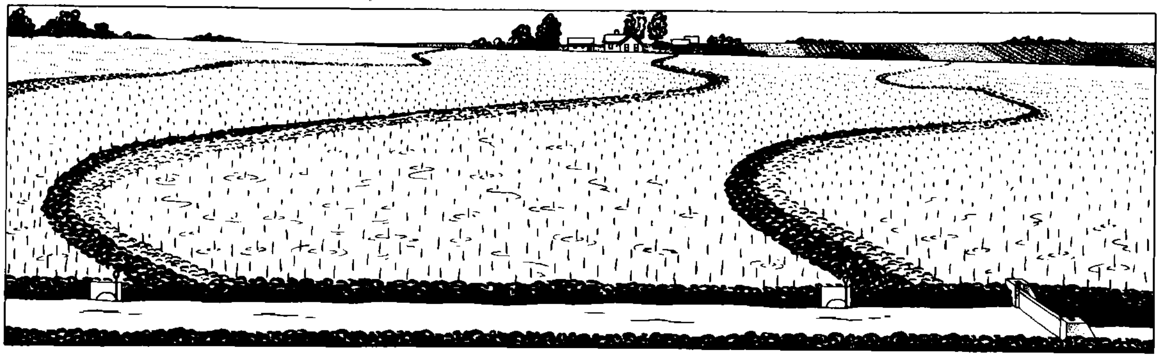


Figure 3-17.--Contour-levee irrigation.

area and is allowed to remain until it has infiltrated the soil to the desired depth. If the irrigation is for soil-moisture replenishment, the excess water is then drained off immediately. If the irrigation is for weed control on riceland, the water is impounded at a minimum depth of 3 inches and a maximum depth of 8 inches or less for several weeks.

Size of the unit area depends on the size of the available irrigation stream, soil intake characteristics, and topography of the field. Generally a stream of 1 cubic foot per second is required for each 2 acres for rapid flooding. Drainage is provided by placing pipe culverts in the drainageways through each levee. Water is held at the desired level by small weir-type spillways in the levees, allowing excess water from one area to spill over into the area immediately below.

Adaptability.--For successful contour-levee irrigation, soils should be medium to fine textured (0.5 intake family or less). For rice the soil should have a saturated permeability rate of 0.01 inch or less per hour or have a restricting layer of this rate just below the crop's root zone. The surface should be smooth and reasonably uniform and have a maximum slope of 1 percent, but slopes of less than 0.5 percent are preferred.

The contour-levee method is particularly suited to rice and can be used for irrigating cotton, corn, soybeans, small grains, pasture grasses, and hay crops. The crop to be irrigated must be able to stand in water for 12 hours or more without damage. Irrigation water must be available at a rate that permits rapid flooding of the areas enclosed by the levees. A minimum stream of 0.5 cubic foot per second per acre for the largest of the areas should be available.

Important Features.--Uniform distribution of irrigation water is easily obtained. A field application efficiency of 80 percent or more can be obtained with a well-planned and well-operated system. Although excess water must be drained, there is usually opportunity to reuse it on areas of lower elevation. Tail-water or runoff losses are limited to the water removed from the lowest area in the field. Since maximum use can be made of any rainfall, seasonal irrigation requirements are reduced to a minimum.

Adequate surface drainage facilities are an essential part of this system, and they can be provided at little extra expense. Generally the same facilities are used to apply water and to remove it. The amount of labor required is low compared with that required for most other methods. The controls are simple and easily operated, and irrigators with little experience can handle large irrigation streams. If only a moderate amount of land smoothing or leveling is needed, the initial cost is low compared with that of most other acceptable methods. The cost of water-control structures is comparable to that of the least expensive structures used in other surface methods.

Limitations.--This method is not generally suitable for use on soils of moderate to very rapid permeability. Irrigations of less than 2 inches are difficult to apply. Large irrigation streams are required. Irrigation water must be of good to excellent quality since the slowly permeable soils to which the method is suited accumulate salts rapidly and are difficult to leach. Land smoothing or leveling is usually required for uniform distribution of irrigation water, drainage, and operation of farm equipment. Many crops cannot be successfully irrigated if they are susceptible to damage by flooding at any stage of growth. Levees may be damaged extensively by waves if water must be applied before vegetation is established.

Contour-Ditch Method

Description.--Contour-ditch irrigation is a form of controlled surface flooding. Irrigation water is distributed from ditches running across the slope approximately on the contour (fig. 3-18). Water is diverted from the ditches by temporary dams. As the water rises, it is discharged through controlled openings in the ditch bank, by siphon tubes, or over a uniformly graded lower lip of the ditch. Water flows as an unconfined sheet down the slope from one contour ditch to the next, and runoff is collected in lower ditches for reuse. Water is applied to successive strips between ditches until the field has been irrigated. The width covered by each setting of the dams depends on the stream size available. A stream of 1 cubic foot per second usually covers a strip about 100 feet wide. The spacing between contour ditches (80 to 300 feet) is governed by topography, soil intake rate, and average net irrigation application.

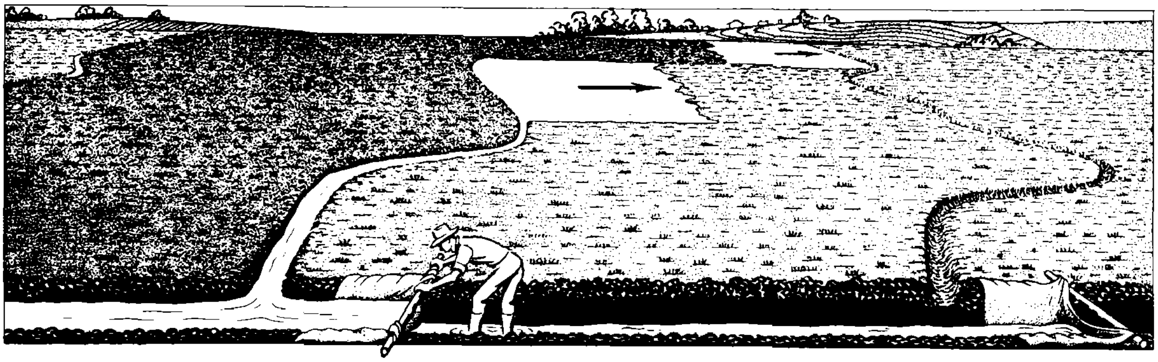


Figure 3-18.--Contour-ditch irrigation.

Adaptability.--This method is suitable for irrigating all close-growing, noncultivated crops except those grown in ponded water. Legumes, grasses, and small grains are the crops commonly irrigated by this method. Contour-ditch irrigation can be used for soils in the 0.1 to 3.0 intake families. Slowly permeable soils permit the widest spacing between ditches, and the application efficiency for a low net irrigation is high. Light-textured soils require close spacing of contour ditches, and the application efficiency is low.

This method is suited to slopes ranging from 0.5 to 15 percent. If erosion from rainfall is a hazard, the maximum slope is 4 percent. If soils and topography permit land leveling, contour ditches are seldom used on slopes of less than 1 percent. The maximum slope for moderately light to coarse textured soils is 4 percent. On slopes of 2 to 4 percent, if erosion from rainfall is a hazard, this method can be used only for sodforming crops.

Important Features.--Installation costs are among the lowest for all application methods. Little surface preparation is required on irregular topography. For annual crops the ditches can be easily filled to facilitate harvesting.

Limitations.--Irrigation efficiency is generally low. With careful management an application efficiency of 50 to 65 percent is possible. Small streams are not easily used. The spacing between ditches may vary considerably, causing different lengths of run. Extra labor is required for adjusting sets to get the proper depth of application and to reuse waste water. The close and irregular spacing between ditches hampers harvesting, especially of hay crops. Young crops may be damaged on soils that bake or crust. If rainfall erosion is a hazard, ditches cannot be installed until a crop is established, which eliminates the possibility of preplant irrigations.

Graded-Furrow Method

Description.--Graded furrows are small channels having a continuous, nearly uniform slope in the direction of irrigation (fig. 3-19). They are used in irrigating cultivated crops planted in rows. There are one or more furrows between crop rows except for bedded crops, in which the

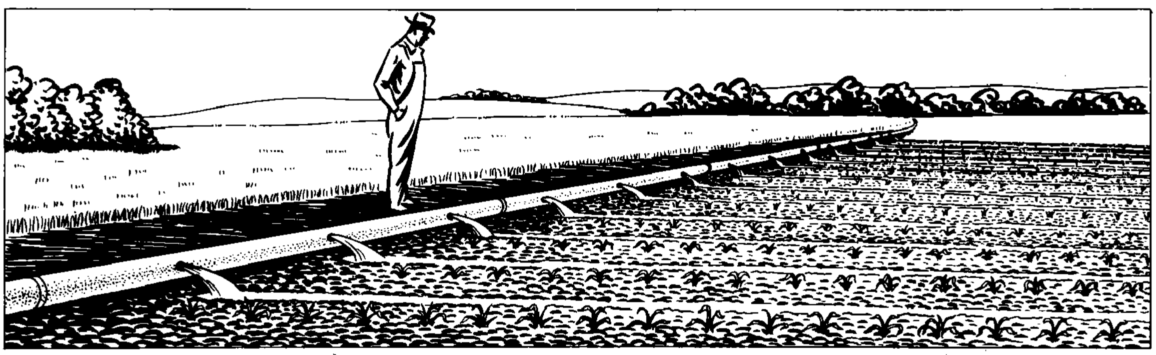


Figure 3-19.--Graded-furrow irrigation.

furrows are along each pair of rows. Size and shape of the furrows depend on the crop grown, equipment used, and spacing between crop rows.

Water flowing in the furrows soaks into the soil and spreads laterally to irrigate the areas between furrows. The length of time that water must be run in the furrows depends on the amount of water required to refill the root zone, intake rate of the soil, and rate of lateral spread of water in the soil. For most soils the initial irrigating streams must greatly exceed the intake rate to advance rapidly. Therefore, when water reaches the lower end of the run, the streams must be adjusted or cut back to prevent excessive waste from surface runoff or provisions must be made to recover tail water. But for low-intake-rate soils that crack when dry, it is not usually necessary to cut back the streams.

Adaptability.--The graded-furrow method can be used to irrigate all cultivated crops planted in rows, including orchard and vineyard crops as well as all field and truck crops. Graded furrows can be used on all soils except sands that have a very high intake rate and provide very poor lateral distribution of water between furrows. But they must be used with extreme care on soils that have high concentrations of soluble salts. To keep excessive amounts of toxic salts from accumulating in the areas between furrows, it may be necessary to use some surface-flooding method to leach salts from the root zone before this method can be used successfully.

This method is best suited to sites where the furrow grade does not exceed 1 percent. But in areas where erosion from rainfall is not a problem, the grade can be as much as 3 percent. In areas of intense rainfall, the furrow grade may need to be reduced to 0.5 percent or less to minimize the erosion hazard. On smooth, uniformly sloping fields, crops can be planted across the slope to reduce the furrow grade. Furrows also are used on graded benches built across the slope.

Important Features.--Both large and small irrigating streams can be used by adjusting the number of furrows irrigated at any one time to fit the available flow. Therefore any type of water delivery, from continuous flow to full demand, can be used. Field efficiency is high if water management is good. In areas where surface drainage is necessary, the furrows can be used to dispose of runoff from rainfall rapidly.

Limitations.--Labor requirements for the graded-furrow method are high. Flow into each furrow must be carefully regulated for uniform water distribution and minimum waste. Fields must be well leveled and facilities for collecting and disposing of surface runoff must be installed. Also, the method is not suitable for applying the very light irrigations needed for seed germination or for very shallow rooted crops grown on soils with a high intake rate.

Contour-Furrow Method

Description.--The contour-furrow method is similar to the graded-furrow method in that irrigation water is applied by furrows, but the nearly level furrows carry water across a sloping field rather than down slope (fig. 3-20). The contour furrows are curved to fit the land surface. They have just enough grade to carry the irrigation stream. Head ditches or pipelines are run downhill or slightly across the slope to feed the individual furrows.

Adaptability.--This method can be used on most sloping soils except light sandy soils and soils that crack. The ridges between furrows in sandy soils may break and wash out, overloading the furrow below, which also breaks. This may continue all the way down the slope, causing heavy erosion damage. Soils that crack provide channels for water, causing similar downslope furrow breaks. This method is particularly suited to fields of uniform slope in both directions because most of the furrows can run completely across the slope and there need be few point rows.

The contour-furrow method can be used for nearly all cultivated crops planted in rows. In arid sections deep-furrowed row crops grown on medium- and fine-textured soils can be irrigated if the slope does not exceed 6 percent. On light-textured soils, the slope must not exceed 4 percent because of the danger of furrow breaks. For shallow-furrowed crops, the slope must not exceed 3 percent. For citrus and deciduous fruits, cane berries, vineyards, and nut trees, the slope can be steeper since the furrows are not disturbed by cultivation.

Important Features.--The contour-furrow method can be used to irrigate safely land too steep for downhill furrows, thus reducing the erosion hazard. Good distribution of water is possible because large irrigating streams can be used in the nearly level furrows and water reaches the end of the furrows quickly. This also reduces the time of irrigating. Good efficiency can be attained if the system is properly laid out and good water management practices are followed.

Limitations.--This method must be watched carefully to guard against furrow overflow and washout. In areas of intense rainstorms, rainfall probably causes more breakthroughs than irrigation water. The runs should be short enough to dispose of the runoff safely without breaking the furrow. Grassed waterways and structures are usually needed to carry

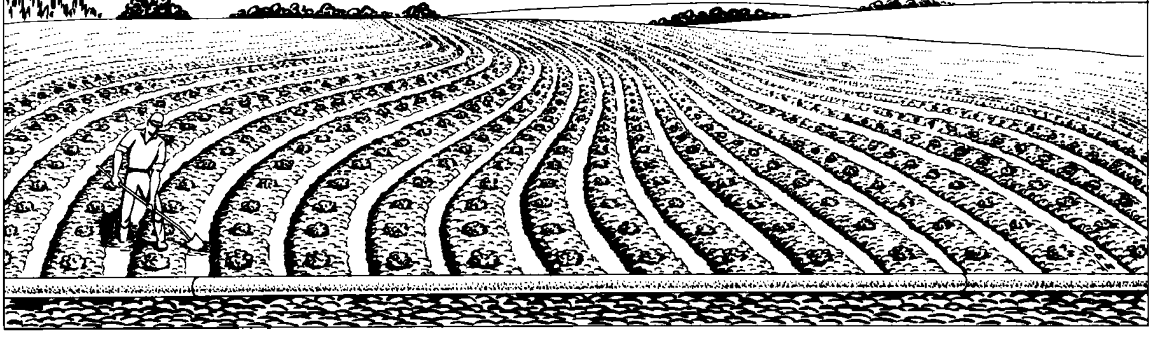


Figure 3-20.--Contour-furrow irrigation.

surplus water down the slope. For a crop like corn, all furrow breaks must be repaired by hand after the corn is laid by. Contour-furrow irrigation used in conjunction with parallel terraces provides additional insurance against breakthroughs.

Head and tail-water ditches must be protected because they run downslope and generally the grade is erosive. Considerable time is necessary to lay out a field, and planting and tillage must be done very carefully. Equipment used in planting, cultivating, and harvesting must turn on the crop at the end of point rows.

Level-Furrow Method

Description.--Level furrows are small channels without grade formed by farm equipment and used to irrigate crops planted in or between the furrows (fig. 3-21). The level-furrow method of water application requires the rapid introduction of irrigation water. A stream as large as the furrow can contain is turned into the furrow until the gross application has been made. The water, which is at uniform depth throughout the furrows, stands until absorbed by the soil. Lateral or capillary movement of water through the soil distributes the water to areas between furrows.

Adaptability.--The level-furrow method is best suited to soils having a moderate to slow intake rate (2.0 intake family or less) and a moderate to high available water holding capacity. The best field layouts for level furrows are on smooth uniform slopes. Row crops are the crops most easily irrigated by level furrows, but drilled or sown crops can be irrigated effectively if the soil has been furrowed and ridged before planting. In areas where rainstorms occur in such intensity and duration that the water-storage capacity of the furrow may be exceeded, border dikes are also needed.

Important Features.--The amount of water applied can be adjusted to meet seasonal variations by changing duration of application or size of furrow stream, or both. No change in layout is needed. High application efficiency can be obtained with this method if it is properly designed and operated. No irrigation water need be lost through runoff.

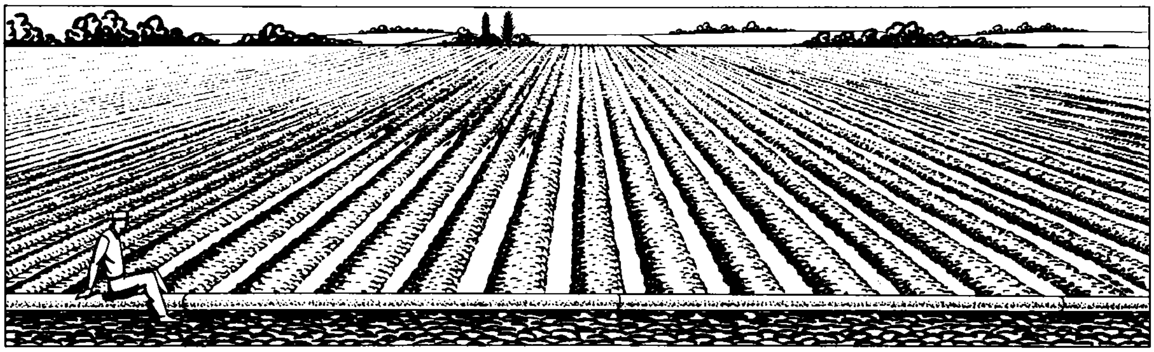


Figure 3-21.--Level-furrow irrigation.

Unless winds of high velocity affect the advancing stream, the field ditches or other conveyance structures can be spaced at twice the design furrow length since water can be introduced at both ends of the furrows. This reduces cost of constructing and maintaining the delivery system, and farm machinery can travel farther before turning. Maximum use can be made of rainfall even if storm intensity exceeds the intake rate. Provisions for disposal or reuse of tail water are not needed. Leaching can be easily accomplished. This method can be automated easily.

Limitations.--In areas where wind velocity exceeds 15 to 20 miles per hour, it is difficult to apply irrigation water if the wind direction is opposite to the direction of water flow in the furrow. Since wind erosion is usually a problem in such areas, row and furrow length should be normal to the prevailing wind direction if practical. If the furrow length is parallel to the prevailing wind direction, water should be applied at the upwind end of the furrows.

Furrow capacity must be large enough to control stream flow. Furrows should be able to contain approximately one-half the volume of the net irrigation application. Sets must be changed often. For efficient operation of a system using this method of water application, it is essential that tillage operations maintain the surface topography and the furrow shape and cross section.

Corrugation Method

Description.--Corrugation irrigation is a partial surface flooding method. Irrigation water does not cover the entire field but is applied in small channels or corrugations evenly spaced across the field (fig. 3-22). Water flowing in the corrugations soaks into the soil and spreads laterally to irrigate the areas between corrugations. The corrugations should be spaced to permit an adequate lateral spread by the time the desired amount of water has infiltrated the soil.

The length of time that water must be run in the corrugations depends on the amount of water required to refill the root zone and on the intake rate of the soil. Initial irrigating streams must greatly exceed the intake rate of the soil in order to advance rapidly. Therefore, when water reaches the lower end of the run, the streams must be adjusted

Figure 3-22.--Corrugation irrigation.

or cut back to prevent excessive waste from surface runoff or provisions must be made to recover tail water.

Adaptability.--Corrugation irrigation is best suited to areas of low rainfall and smooth fields that have slopes between 1 and 8 percent. It can be used on irregularly sloping sites, but the corrugations must have a continuous slope in the direction of irrigation and the cross slope must be such that breakthroughs from both irrigation water and rainfall runoff are held to a minimum. The cross slope usually should be considerably less than the slope in the direction of irrigation. The use of corrugations in humid areas usually creates a serious erosion hazard.

All close-growing, noncultivated sown or drilled crops except rice and other crops grown in ponded water can be irrigated by this method. Legumes, grasses, and small grains are commonly irrigated by this method, which is used also for irrigating noncultivated orchards and vineyards having grass or legume cover crops.

Corrugations are best used on fine to moderately coarse textured soils. They are not suitable for coarse-textured high-intake-rate soils or saline soils. The method is especially good for irrigating soils that bake or crust. Since only a small part of the soil surface is wetted, crusting is greatly reduced. Corrugations often are used in establishing crops to be irrigated by the graded-border method later.

Important Features.--Irrigating streams can be large or small since the number of corrugations irrigated at one time is simply adjusted to fit the available flow. Little land preparation need be done, and often new land can be cleared and put into production the first year. On well-leveled fields reasonably high efficiency can be obtained easily if proper water management practices are followed.

Limitations.--Labor requirements are high. Irrigation streams must be carefully regulated for uniform water distribution and minimum waste. Fields must be corrugated at least once every year and in many cases, more than once. Equipment operating costs also are high. The rough field surface is difficult to cross with equipment and causes excessive damage from vibration. In addition, the method is not well suited to gentle slopes. Seldom should it be attempted on slopes of less than 1 percent. Therefore it is not generally suited to areas that have high rainfall during the irrigation season.

## Subirrigation

Water is applied beneath the ground surface to create an artificial or perched water table over some natural barrier that restricts deep percolation. Moisture then reaches the plant roots through capillary movement.

Subirrigation Method

Description.--Irrigation water is introduced through open ditches, tile drains, or mole drains (fig. 3-23). The water table is maintained at some predetermined depth below the ground surface, usually 12 to 24 inches, depending on the rooting characteristics of the crop grown.

Open ditches are probably most widely used. Feeder ditches are excavated on the contour and spaced close enough to insure control of the water table. They are connected to a supply ditch that runs down the predominant field slope and has control structures as needed to maintain the desired water level in the feeder ditches.

A tile system is expensive and generally is used only for high-value crops. Parallel tile lines are laid 24 inches to 40 inches deep at a nearly level grade that approximately parallels the ground surface. They are spaced close enough to insure almost complete control of the water table. In general the upper ends of these feeder lines are connected to a supply line into which water is introduced. The lower ends are connected by an outlet tile which is used to carry excess irrigation water and storm water to a satisfactory outlet. Controls are placed in each feeder line to regulate the water-table level.

Mole drains have been used successfully as feeder lines only in organic soils. They are formed by pulling a bullet-nosed cylinder through the soil at a minimum depth of 30 inches to prevent closure of the holes by compaction during farming operations. The lines are 12 to 15 feet apart and are connected by an open ditch that serves both to introduce irrigation water into the mole drains and to remove water from them for drainage. Well-constructed moles in suitable soils give effective service for 5 to 8 years.

Adaptability.--The subirrigation method is suited to soils having reasonably uniform texture and permeable enough for water to move rapidly both horizontally and vertically within and for some distance below the crop's root zone. The soil profile must also contain a barrier against excessive losses through deep percolation, either a nearly impermeable layer in the substratum or a naturally high water table on which a perched or artificial water table can be maintained throughout

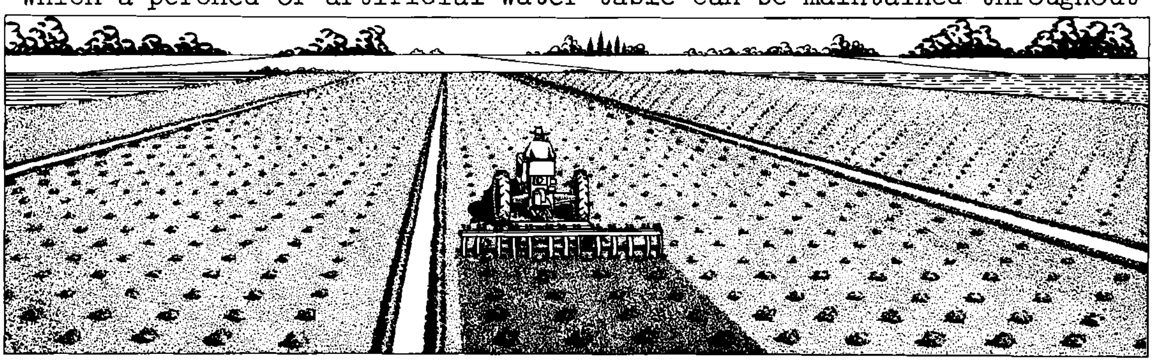


Figure 3-23.--Subirrigation.

the growing season. Topography must be smooth and nearly level or the slopes very gentle and uniform. The subirrigation method is suited to irrigating vegetables, most field crops, small grains, pasture grasses, most forage crops, and flowers.

Important Features.--This method can be used for soils having a low water-holding capacity and a high intake rate where surface methods cannot be used and the cost of sprinklers is excessive. The water level can be maintained at optimum depths for crop needs at different growth stages. Water loss by evaporation from the soil can be held to a minimum. Weed seeds are not carried over the surface by irrigation water.

The subirrigation distribution system can also be used as the drainage system. Tile feeder lines generally provide better drainage than open-ditch feeder lines. Labor requirements are less than for any other irrigation method. Labor is required only for regulating stream flow into the system, regulating water-level control structures, and tending the pump if pumping is required.

Limitations.--Since this method requires an unusual combination of natural conditions, it can be used in only a few areas. Water having a high salt content cannot be used. In some arid areas soils become saline unless adequately drained. Choice of crops is limited in some areas. Deep-rooted crops such as deciduous orchard trees and citrus trees generally cannot be subirrigated.

## Irrigation Water Conveyance

Irrigation water must be made available to each part of the farm irrigation system at a rate and elevation that permits proper operation of the selected methods of water application. Irrigation water should be conveyed as economically, efficiently, and safely as possible. The delivery part of the farm irrigation system must be large enough to furnish the required irrigation water to meet crop demands during peak-use periods. If the water is delivered on a rotation or turn basis, the system must be large enough to allow delivery of the water in the time allotted. Plans should provide for future needs and expansion.

The type of conveyance facilities varies with the method of application. Sprinklers require pressure pipe, mains, and laterals, and subirrigation uses either ditches or tile. The contour-levee method generally uses a head ditch and levees, and the furrow and border methods require either ditches or pipelines with siphon tubes, gated pipes, or other forms of takeouts.

Conveyance facilities generally are either surface ditches with all the necessary grade-stabilization and water-control structures or pipelines. They must be accessible for operation and maintenance. They must be able to provide water to every part of an irrigated area. They should be located so that they interfere with farming operations as little as is practical.

## Ditches

Irrigation ditches are open channels used to carry irrigation water to its point of use. They are used more than any other type of conduit. Small inadequate ditches without proper control structures and maintenance probably are the source of more trouble in operating an irrigation system than any other cause.

Ditches that carry irrigation water from the source of supply to one or more farms are known as canals and laterals. They are generally large and should always be permanent installations. Field ditches convey water from the farm source of supply to a field or fields within the farm unit. They also should be permanent installations.

Head ditches are used to distribute water in a field for surface irrigation. They are laid out at the high end of the irrigation run and are generally perpendicular to the direction of irrigation for furrows and borders. In contour-ditch irrigation and in subirrigation where water is distributed through open ditches, the head ditch runs down the slope and water is released on one side or both. Head ditches can be permanent or constructed each irrigation season. The water surface in head ditches should be above the ground level, 0.5 to 1 foot higher than the ground to be irrigated. If possible, the ditches should be nearly level (less than 0.1 foot fall per 100 feet) so that water can be backed up for a maximum distance, thus requiring a minimum of check dams and labor to control irrigation flow.

Ditches work best in clay or loam soils since seepage is usually less and ditch banks are more stable than those in sands or sandy loams. Open ditches can carry large volumes of water and have the advantage of low cost per volume of water carried. On soils where seepage is not a problem, they are easy to build.

Ditches have some limitations. Losses from seepage and evaporation can be high, and weeds and burrowing animals can cause trouble. Ditches take up valuable space and may hinder farm operations. Their maintenance requirements are higher than those for pipelines.

### Unlined Ditches

Unlined ditches are the most commonly used method of carrying irrigation water, but many are not efficient. Small ditches can be easily built and maintained with farm equipment. They can be built before the irrigation season starts and be removed before harvest, or they can be removed after each irrigation and new ones built for the next irrigation.

In porous soils unlined ditches lose considerable quantities of water by seepage. Soil permeability probably is the most important factor. Losses are greater if the water is carried a long distance and are proportional to the wetted perimeter and depth of water flow in the ditch. Vegetation along a ditch, particularly along permanent ditches, contributes to water loss through transpiration. Rodents and insects cause losses by burrowing in ditch embankments. In addition to the loss of irrigation water, seepage also damages adjoining land by raising the water table.

Grade-control structures are required in ditches if the design flow develops an erosive velocity. On slopes where drop structures must be closely spaced, it may be more economical to use a lined ditch, chute, or buried pipeline. Where ditches cross roads or waterways, it is necessary to install some type of crossing structure.

Lined Ditches

Ditch lining is an effective way to control seepage. Erosion-resistant linings can be used also to control ditch-bottom and bank erosion. For any given flow, lined ditches can be smaller than unlined ditches, which reduces the amount of land they take up. Lining also provides some protection against damage by rodents. Lining protects land against waterlogging and salinity. Depending on the kind, a lining reduces cost of maintenance, insures against interruption in water deliveries, and helps control weeds.

Selecting a lining should be governed by availability of the material and equipment needed to install it, ditch size, climatic and foundation conditions, and whether the irrigation stream is continuous or intermittent. Freezing and thawing damage some kinds of linings as does trampling by livestock and a fluctuating water table. Vegetation will damage some linings unless growth is controlled.

Many kinds of materials are used. Concrete is probably the most popular, but asphaltic materials, membranes, metals, chemical sealants, and impermeable earth materials are also used. Any of these materials make good linings if they are properly selected and are installed according to site conditions.

Concrete Lining.--Portland cement concrete is one of the most widely used materials. If site conditions are favorable, a well-constructed concrete lining gives long service with minimum repair and maintenance costs. Nonreinforced concrete is generally used. Thickness ranges from 1-1/2 to 3 inches, depending on climate and the expected water velocity in the ditch.

Concrete linings withstand high stream velocities and therefore are particularly suitable for erosion control as well as seepage prevention. They are superior to most other linings in resistance to mechanical damage. They are limited to nonexpanding soils where it is possible to get good internal drainage. If concrete linings are to be installed on poorly drained sites, in areas subject to severe frost heaving, or in soils having a high sulfate-salt concentration, they must be specially designed and protected.

If good concrete is available locally, slip-form-placed portland cement concrete is probably the most economical lining (fig. 3-24). In this method concrete is placed by a specially designed machine. The slip form rides on and is guided by the subgrade as it is pulled forward by a tractor or winch. Freshly mixed concrete is poured through a hopper so that the slip form distributes concrete to the sides and bottom of the ditch. The rear section of the slip form is a strike-off or screening mechanism. Thickness of the concrete lining is determined by the difference in height between the bottom of the rear section and the bottom of the front section. Ready-mixed concrete is probably best to use because its quality is easy to control and sufficient volume can be available at all times to keep the form in operation as continuously as possible.

For a farmer who wishes to dig and line his own ditches, panel-formed lining has advantages. After digging the ditch to grade, he sets guide-form panels about 10 feet long and pours concrete in every other panel, skipping a 10-foot section (fig. 3-25). When the concrete is set, he moves the guides and pours the skipped panels. The bottom in each section is poured first, and then the fresh concrete is screeded up the slope.

Pneumatically applied mortar known as shotcrete is sometimes used to line and resurface old concrete and rock cuts. Special machines are required, and the concrete mix must be carefully controlled. It is possible to get a strong durable lining but, except for very thin linings, it is more costly than slip-form concrete.

Asphalt Lining.--Asphalt can be used for seepage-control linings, either as asphaltic concrete or in sheets, planks, or membranes. Asphaltic concrete consists of sand and gravel bound together with asphaltic cement. It is similar to portland cement in many respects, but it does not last as long and withstands lower velocities. Asphaltic concrete is not so hard as portland cement concrete and is therefore more subject to mechanical damage. In many places the subgrade must be sterilized to prevent vegetation from growing through the lining and causing deterioration. Hot-mix asphaltic concrete has given fairly satisfactory results, but special equipment is needed to blend and place it. It can be placed by a slip form or heated screed moved slowly along the ditch by winch or tractor.

Prefabricated asphalt planks are also available for lining ditches. They are 2 to 4 feet wide by 8 to 12 feet long and one-fourth to one-half inch thick. They should be laid in warm weather so that they soften enough to conform to the shape of the ditch. Generally they are installed transversely. But if they are lapped, the lap is downstream so that water puts no stress on the joints. If the sheets are butted, a cap strip is used to cover the joints. Planks should be buried in the berm for anchorage. Unless the lining is well anchored, it sags on the slope and wrinkles.

WYO-648

Figure 3-24.--Placing concrete ditch lining by slip-form method.

Bn-12711

Figure 3-25.--Constructing concrete ditch lining by alternate-panel method.

Prefabricated asphalt-membrane linings can be installed in small irrigation ditches by unskilled labor. The liners are one-eighth to one-fourth inch thick and come in rolls 40 inches wide. They are designed to be handled and placed in much the same manner as rolled roofing with lapped and cemented joints. These linings are usually covered with earth and gravel, but if the irrigation stream is to have a high velocity, they can be covered with shotcrete or macadam. The liner is buried in a trench on the berm paralleling the ditch to hold the liner in place. Various kinds of asphalt-membrane linings are available, such as asphalt-coated jute, asbestos fiber with asphalt coating, fiber-glass mat filled with asphalt, or other organic materials saturated and coated with asphalt.

Asphalt lining can be sprayed on. The cross section of the ditch is made larger than required. The asphalt is then sprayed over the ditch and covered with 6 to 9 inches of protective earth covering. Sprayed-on lining can be used only in ditches having a stream velocity of 3 feet per second or less. Special equipment is required for spraying the hot asphalt. If properly installed, sprayed-on lining will give reasonably good service for at least 10 years.

Flexible-Membrane Lining.--Strips of a specially formulated film in sheet form, usually rubber or plastic, can be joined with an adhesive and used as a ditch lining. The subgrade should be firm, smooth, and free of vegetation. All sticks, clods, and debris should be removed to protect the lining against punctures.

In permanent ditches the membrane generally is buried, which lengthens its usable life. The ditch is overexcavated, and the lining is placed and then covered with soil or gravel. The covering material must be carefully selected and placed on the membrane so that there is no damage during construction. Flexible membranes can be used only in ditches in which the stream velocity does not exceed 3 feet per second. The earth covering, 6 to 9 inches thick, serves to weight the liner and hold it in place when the ditch is not filled with water as well as to minimize mechanical damage. Since weeds may pierce a plastic lining, a sterilizing agent is used on the subgrade before the membrane is placed. Butyl rubber resists deterioration due to exposure, biological activity, and root penetration. Maintenance work must be done very carefully to keep membrane linings from being damaged.

Prefabricated Metal Lining.--Prefabricated metal liners can also be used to control seepage and erosion in irrigation ditches. They come in convenient lengths for easy handling. The sections are battened together, and a special sealant is used to make all joints watertight. These liners have an advantage in isolated areas where it is difficult to bring in other kinds of lining material. They should provide many years of trouble-free service, and construction and maintenance costs are low. But they should not be installed in areas in which the water has a high concentration of salt or other chemicals injurious to the metal without a coating specifically formulated to protect them from these chemicals.

They are suited to small ditches that have a bottom width of no more than 3 feet. The bank of the ditch should be high enough for the top edge of the lining to be firmly anchored in the ditch bank. Weeds are no problem, and the liners are resistant to tunneling by burrowing rodents. If freezing temperatures are common, the foundation must have adequate drainage to prevent water accumulating under the lining.

Chemical Sealants.--Chemical sealants can be used to make ditch subgrades nearly impermeable to seepage. They are effective if the ditch perimeter is moist most of the year but are less effective if the ditch dries out. Cracking of the soil breaks the membranes formed by the sealant and provides channels for seepage.

Chemical sealants can be used on any soil but are not particularly suited to sandy soils. Some are not satisfactory because of short life, high cost, or toxicity to animals and crops. These sealants are waterborne and therefore must be put in the ditch water, usually at a point of disturbance such as a drop structure to facilitate mixing the sealant with the water. Some supplemental mixing may be required.

One application method is to put the sealant into a flowing ditch with the water checked at a ditch structure to reduce the velocity of flow. This allows more time for the sealant to act on the subgrade in a given reach than is possible under normal flow. Ponding is another method. Treated water is allowed to stand in successive ponds formed in a ditch by temporarily sealing ditch structures or by placing temporary dams between structures. The water is allowed to remain in each pond long enough for the sealant to act on the soil. Although this method may be more costly, the sealing effect is somewhat better than that of the flowing-water method.

Bentonite.--Bentonite is a low-cost material similar in appearance to ordinary ground clay. It swells 12 to 15 times its dry size when wet and fills the voids through which water seeps. The three general methods of using bentonite for sealing ditches are by membrane lining, soil-mix lining, and sedimenting.

In the first method bentonite is spread as a membrane, 1 to 2 inches or more thick, over the canal subgrade and then covered with a 6- to 12-inch protective blanket of stable earth or gravel. If properly placed, the membrane lining controls seepage for many years.

In the soil-mix method, bentonite is spread evenly over the perimeter of the ditch and then mixed with the upper 3 to 6 inches of soil by disk, spiked-tooth harrow, or rake. The treated soil is then rolled or tamped until a good soil density is obtained. In some places a protective cover of stable earth or gravel is applied.

In the sedimenting method, bentonite is applied in one of three ways. It can be scattered over the surface of the water, dumped into the ditch at intervals before the water is turned in, or put into the ditch water as slurry. The bentonite swells, and the resultant gel fills the voids along the sides and bottom of the ditch. Since it does not penetrate the soil to any depth, it forms a thin coating on the wetted perimeter of the ditch, which reduces seepage. But since bentonite shrinks on drying and is eroded by flowing water, the coating does not last very long.

Earth Linings.--Linings of natural or processed soils often prove economical for reducing seepage and stabilizing sections if suitable materials are available from the ditch excavation or from nearby borrow areas. Compacted earth linings are easily damaged in ditch cleaning and by vegetation, but under ordinary circumstances their initial installation cost is less than that of other types of linings. There are three general kinds of earth linings: Thick compacted earth, thin compacted earth, and material compacted in place. For thick or thin compacted earth linings the porous earth in the ditch must be removed and then replaced by material more suitable for ditches.

A thick compacted earth lining generally is 2 to 3 feet thick, measured normal to the side slope, and 1 to 2 feet thick on the ditch bottom. Because of the cost, thick compacted linings generally are used for large canals and ditches, but in some places they are economical for medium-size and small ditches.

A thin compacted earth lining generally consists of a 6- to 12-inch layer of thoroughly compacted cohesive soils. The lining commonly is covered with a 6- to 12-inch layer of coarse soil or gravel. Thickness of both lining and cover varies with the kind of soil used and the velocity of the water to be conveyed. Soils used for thin compacted linings are gravels with sandy clay binder, clay gravels, sand with clay binder, and clayey sands.

In some places it is possible to compact soils in the ditch banks and bottom enough to reduce seepage losses appreciably. Many fine soils and well-graded coarse soils and fines can be compacted in place. This is particularly true if soils have a fractured structure. Compaction is accomplished by scarifying, adding moisture, and compacting to the required density by sheepsfoot rollers, flat rollers, or other available equipment. The soil should be tested in a laboratory to determine moisture and density requirements and the feasibility of compaction to eliminate seepage.

## Conveyance Structures

Flumes, inverted siphons, elevated ditches, road culverts, and bridges are used to carry water across swales, draws, and roads and along steep hillsides. These structures are necessary to transport irrigation water efficiently.

Flumes.--Flumes are artificial channels supported by substructures, which carry water across areas where ditches are not practical, such as draws or swales or along steep or rocky hillsides. They must be big enough to carry the full discharge of a ditch, and the substructures must be strong enough to support the channel when it is filled with water.

Timber, metal, or concrete ordinarily are used for open flumes. Pipes can be used for closed flumes. Metal or concrete flumes generally are preferred over timber flumes (fig. 3-26). They can be made almost watertight and remain so during their usable life if the supporting structure is well designed to prevent any sagging or shifting of the channel. Reinforced-concrete flume channels are the most nearly permanent as well as the most costly. They also require concrete substructures. Metal pipe flumes are particularly suited to small flows. They can be installed quickly, and some of the dangers of overflow possible in open flumes are eliminated. A pipe flume has the disadvantage that it may be plugged by floating debris.

Substructures commonly are built of timber, steel, or concrete. Timber substructures should be treated with a preservative to extend their life. Concrete or steel substructures generally have a longer service life, need less maintenance, and are not easily damaged by fire.

Inverted Siphons.--Inverted siphons are closed conduits with each end raised, forming a U-shaped structure, that are used to carry water across depressions and drains or under roads and other obstructions (fig. 3-27). They are usually made of corrugated or smooth metal pipe, concrete pipe, or reinforced concrete poured in place. They are particularly suited to conveying water under roads if the water in the ditch is carried above ground. They are often used in place of flumes, particularly for crossing steep wide depressions. They differ from culverts in that the top of the pipe is lower than the water surface and the pipe is always under some pressure. The amount of water they can carry depends on the size and kind of conduit and on the difference in elevation between the water surface at the inlet and at the outlet. Velocity in the pipe should be at least as high as that in the ditch leading to the structure to prevent sedimentation at the bottom of the siphon. Trash racks are needed to keep the siphon open. Properly installed inverted siphons require little maintenance. Since they are underground, they are well protected, especially against flood damage.

Elevated Ditches.--Elevated ditches are open channels built on compacted earth fill to convey water across shallow depressions or to deliver water by open ditch to a high part of a field. The fill material must compact readily but not crack when dry. Elevated ditches generally are used for carrying large flows or in places where they are less costly than flumes, siphons, or pipelines.

The major problems are seepage loss, dry-weather cracks through the ditch bank, difficulty of controlling weeds and rodents, and difficulty of maintenance. For these reasons it is generally best to use pipe conduits if the ditch must be elevated more than 2 or 3 feet. Careful and timely maintenance is necessary because a break in the bank may

WYO-614

Figure 3-26.--Timber-supported metal flume.

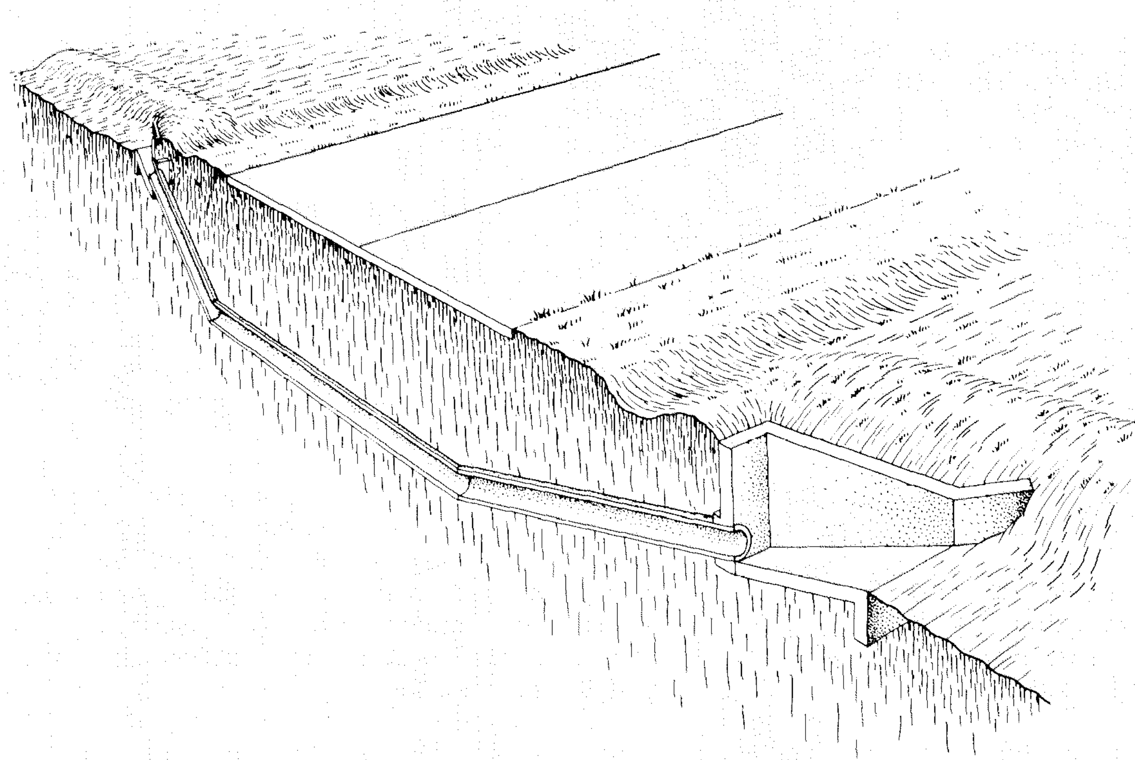


Figure 3-27.--Section of a concrete inverted siphon.

cause serious washouts that will damage the structure and the surrounding area. The higher the fill, the greater the potential damage from breaks or holes made by burrowing animals. The ditches can be lined to lessen this hazard and to reduce seepage. If an elevated ditch crosses a drainageway, a culvert is needed.

Road-Crossing Structures.--Culverts, inverted siphons, or bridges are used to carry water across roads. Culverts are used most often under farm roads because they are generally the least expensive. Corrugated metal, smooth metal, and concrete are used most commonly for culverts in farm ditches. The culverts should be long enough to maintain a roadway of adequate width and must have enough covering to protect the pipe from concentrated loads. Inverted siphons are particularly suited to crossings at which the water surface in the ditch is higher than the road.

Bridges can be used for road crossings over ditches regardless of the elevation of the water in the ditch. They can be built so there is little or no loss of head through the structure.

Grade-Control Structures

Some irrigation ditches are built with enough grade to produce erosive velocities. Such velocities scour the ditch and may cause the banks to slough. The eroded material is deposited downstream, thereby reducing ditch capacity and increasing the maintenance needed. Some protective measures therefore must be used, such as drops and chutes to control grade and linings to protect the banks. But in some places it may be better to use a pipeline instead of a ditch.

Drops.--Drop spillways or pipe drops control ditch velocity by lowering the water abruptly from one level to a lower level. A drop spillway is a weir. Water flows through the weir opening in the headwalls, drops to a nearly level apron spilling basin or to a lower level, and then flows into the downstream section of the channel. For small drops, a simple apron usually is adequate. For higher drops or bigger streams, some type of energy dissipater must be provided. Different kinds of drop structures are shown in figure 3-28.

Large open drops are usually built of reinforced concrete. Reinforced concrete, concrete block, rock masonry, or rot-resistant lumber, such as redwood, cedar, fir, or creosoted pine, can be used for smaller structures. Prefabricated structures made of steel or aluminum are also available. Metal drops should be treated against corrosion. Special cement or alloys may be required if the chemical concentration in the soil is high enough to cause rapid deterioration.

A pipe drop is a section of pipe with a riser equal to the required drop. A fill must be built across the ditch to direct water through the pipe. Corrugated-metal pipe drops are commonly used and are available commercially. Smooth steel, precast concrete, or clay pipe can also be used. Pipe drops are especially suited to small ditches. The fill across the ditch can be widened by adding extra pipe to provide a road crossing if needed, which is an important feature. Pipe drops are more easily plugged by trash than weirs are. The earth fill should be inspected frequently to protect against damage by burrowing rodents.

Chutes.--Chutes are paved or lined, high-velocity, open channels. They can be used as short ditch sections on steep slopes or where drop structures would be so close together that a paved ditch is more practical. The paving or lining material for the chute must be able to withstand high-velocity flow. Chutes are usually built of concrete.

High velocity is a problem if it is necessary to divert some of the flow into farm ditches. If a chute empties into an earth ditch, some kind of spilling basin is needed to slow down and smooth out the flow to protect the ditch. Chutes are expensive and must be designed individually.

## Distribution-Control Structures

Distribution-control structures are required for easy and accurate distribution of irrigation water to the various fields on a farm. Good water control permits efficient distribution and application and reduces labor requirements. Selecting the correct kind of water-control structure and locating it properly is an important part of planning a farm irrigation system.

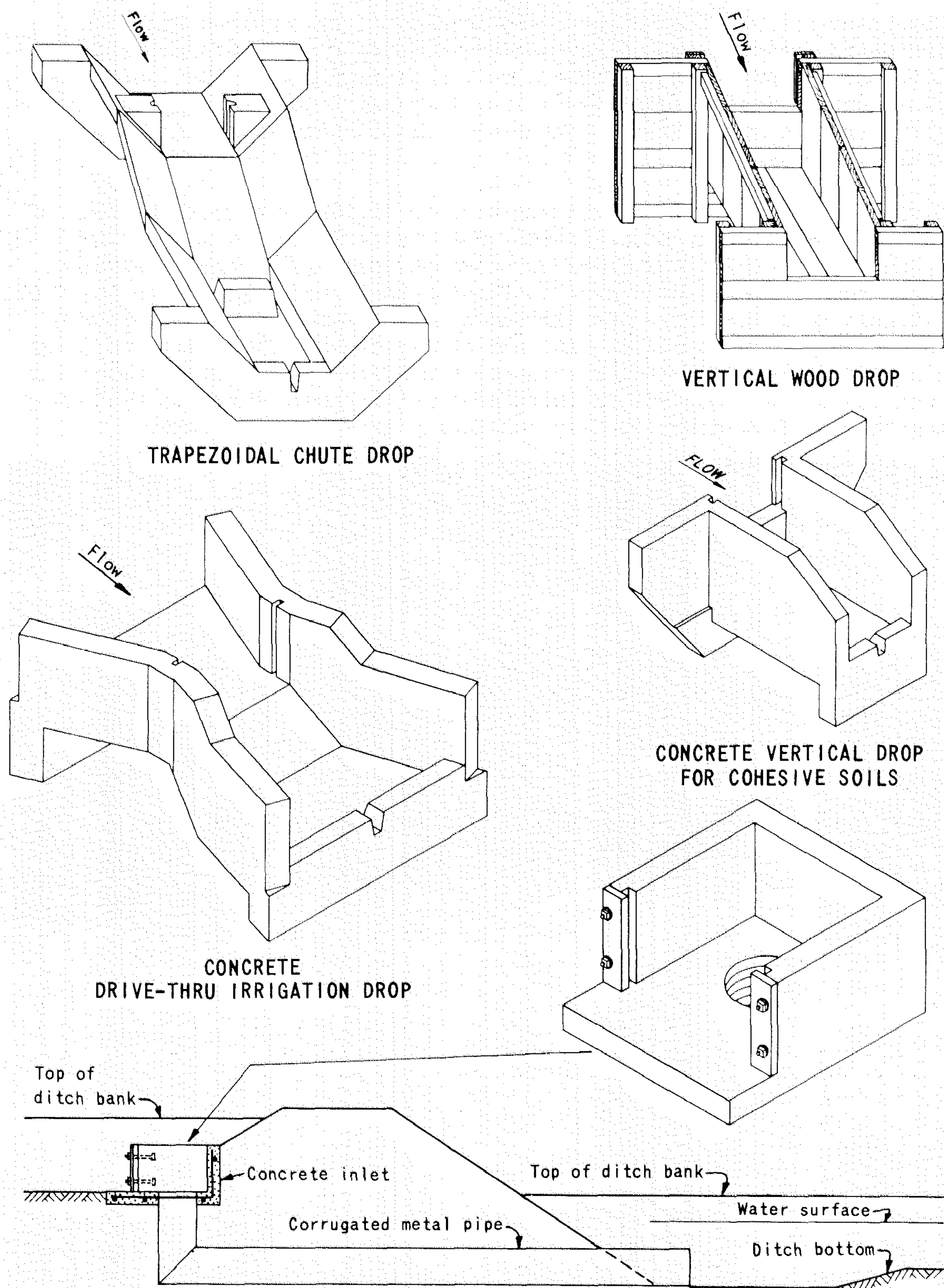



Figure 3-28.--Five drop structures.

Headgate.--Farm headgates are used to divert the required amount of irrigation water from the farm source of supply to the farm field ditches. Headgates may include a weir measuring device that determines flow into a field ditch (fig. 3-29). They may be culvert-type diversion structures equipped with a measuring well or submerged orifices with measuring gages.

Division Box.--Division boxes are used to divide or direct the flow of water between two or more ditches. Water enters the box through an opening on one side and flows out through openings on the other sides equipped with gates of a size to furnish the necessary flow to the field ditches. Division boxes are also used at pumps to control the flow of water from the pump outlet into one of two or more field ditches (figs. 3-30 and 3-31). Concrete or concrete block are the materials generally used for division boxes. Prefabricated metal panels that can be bolted together to form a box quickly and easily are also available.

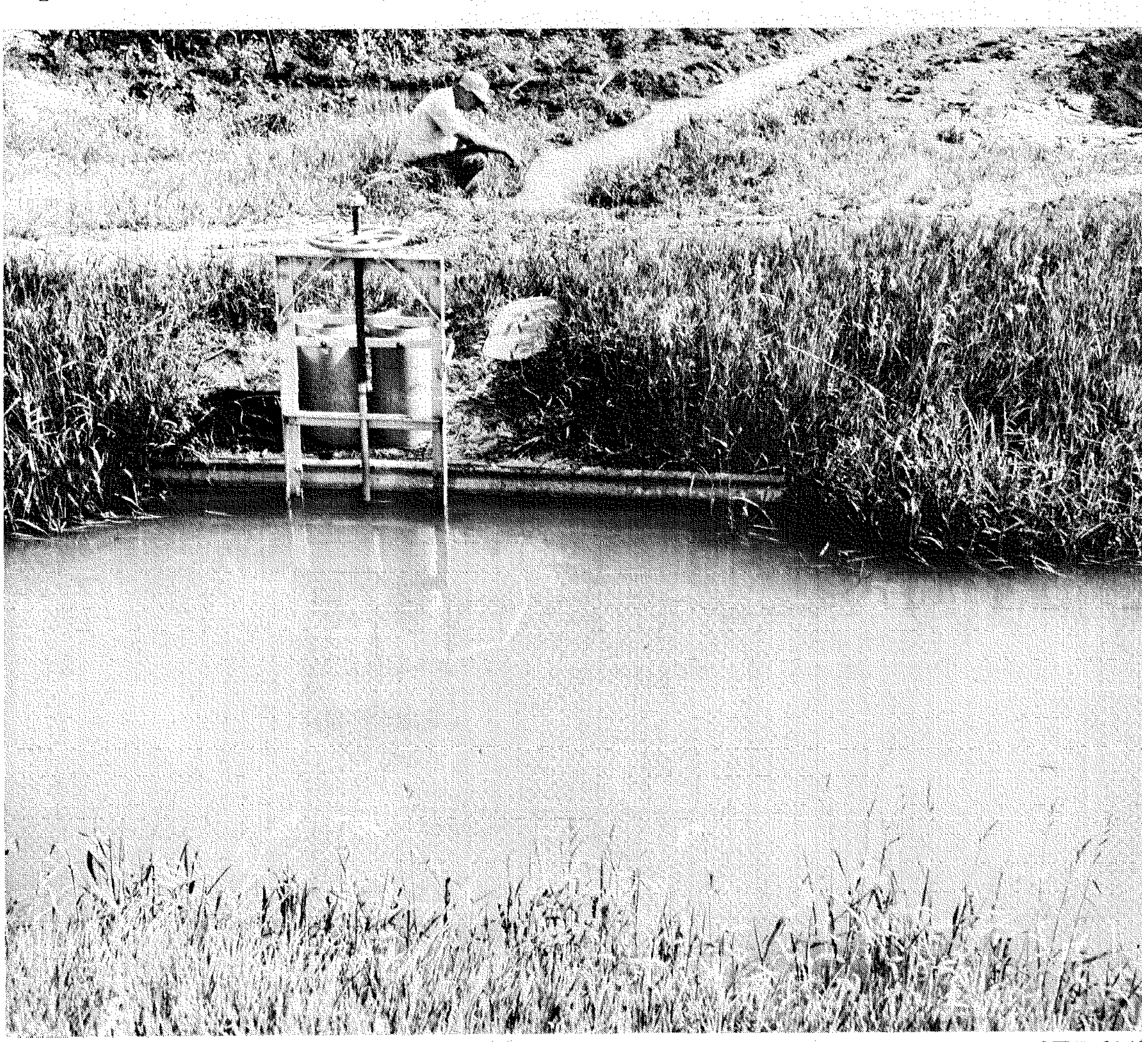


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Figure 3-29.--Headgate equipped to measure water directly from an irrigation canal to a farm ditch.

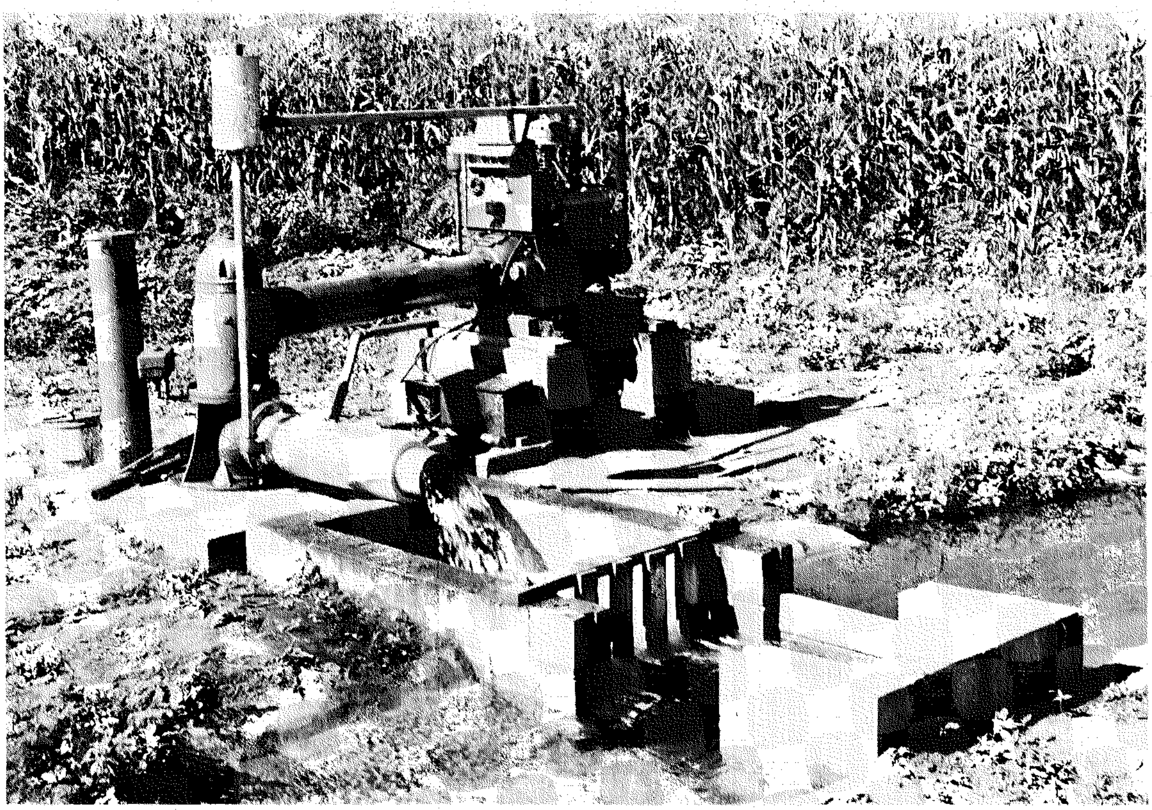

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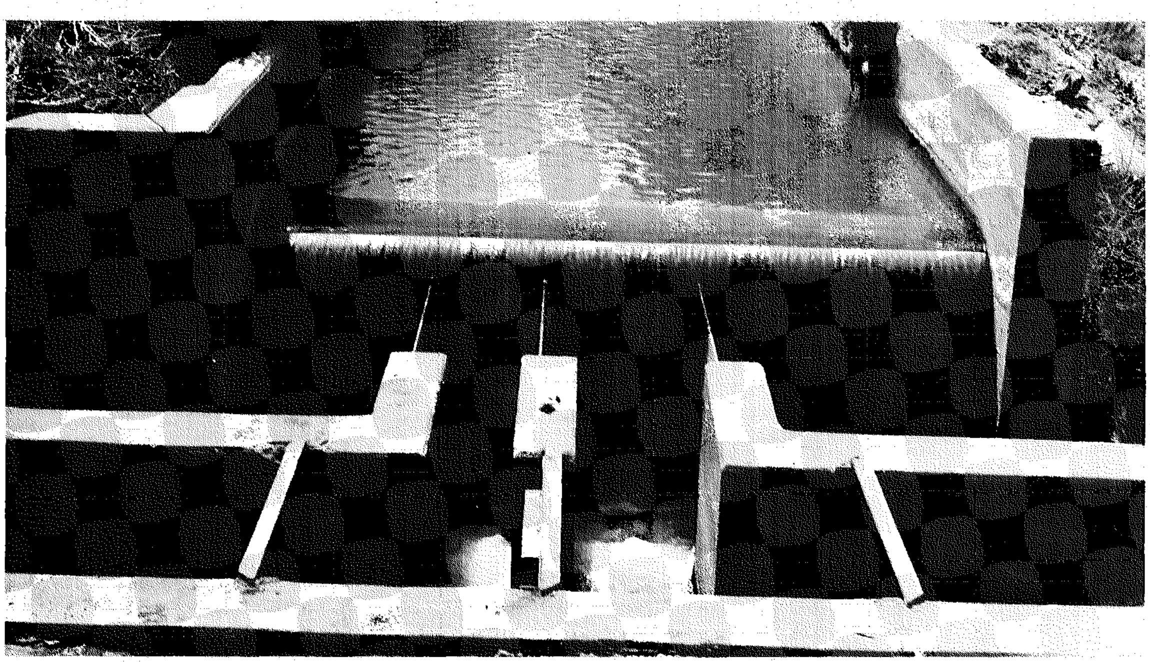
Figure 3-30.--Pump stilling basin and division box.



COLO-11178

Figure 3-31.--Division box with four chambers.

Checks.--Checks are structures placed in a ditch to form adjustable dams to control the elevation of the water surface upstream so that water can be diverted from the ditch. Checks can be permanent or portable. Different kinds of checks are shown in figures 3-32 through 3-39.

A permanent check is a headwall with a weir opening equipped with grooves for flash boards or with metal slide gates for adjusting the upstream elevation of the water surface. Boards can be used as stops. By changing the number or height of the boards, the upstream elevation can be controlled as well as the degree of overpour. If slide gates are used, the upstream elevation is controlled by raising the gate so that the excess water flows under the gate.

Permanent checks used in the more nearly permanent ditches generally are made of concrete, wood, or steel. Checks can also be combined with drops. Permanent overfall checks in unlined ditches should have an apron for the overflow to prevent scouring that might wash out the check.

Portable checks can be removed after they have served their purpose for irrigating a given area and reset downstream for irrigating another area. They are generally made of canvas, plastic, rubber, or metal. Metal checks are forced into the sides and bottom of a ditch, the others are dug in and then backfilled so that they do not wash out. Portable checks can also be used in concrete- or asphalt-lined ditches. Portable metal checks usually are laid on a slant in lined ditches and are held in place by the weight of the water.

Relifts.--Relifts are used to lift water by pumping from a ditch to a ditch at a higher elevation. A pump sump is built in the lower ditch where the pump is to be located. A pump discharge bay of concrete, concrete block, lumber, or metal is generally needed in the upper ditch to prevent damage from the pump discharge. Relifts are used if the farm water supply is not high enough to reach all areas of the farm by gravity flow.

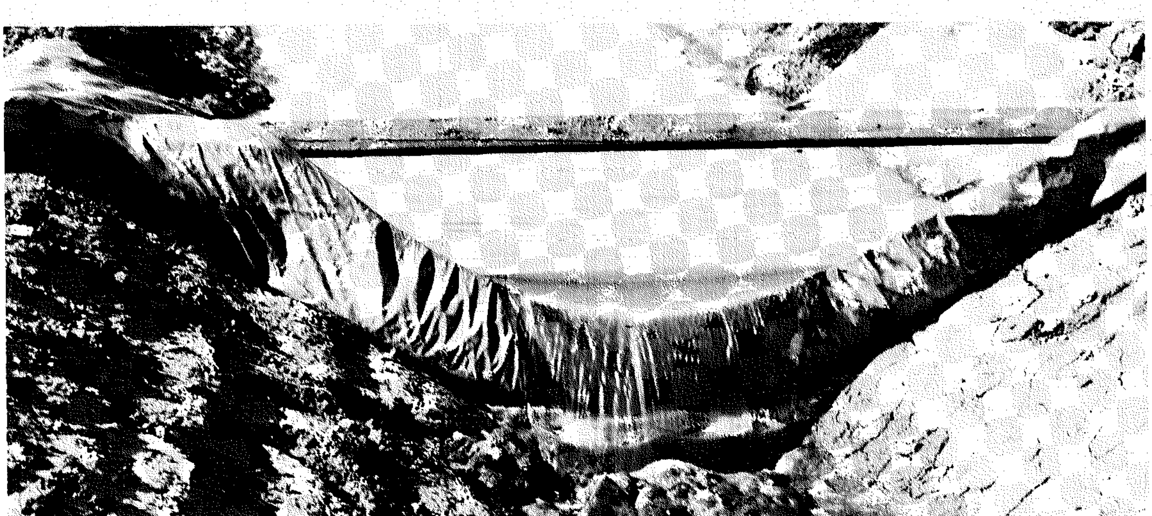
## Application-Control Structures

The amount and rate of flow of irrigation water applied to a field must be adjusted to the water-holding capacity and intake rate of the soils, thus saving both labor and water. Various kinds of structures are available for controlling and adjusting the flow of water from field head ditches to individual furrows, corrugations, border strips, contour ditches, and subirrigation ditches.

Turnouts.--Turnouts are boxes or orifice-type structures in the bank of a head ditch that provide and control the flow of water from the head ditch into border strips, contour levees, and contour ditches. They usually have some type of simple slide gate to regulate the flow. Wooden boxes and concrete or metal pipe are generally used for turnouts (figs. 3-40 through 3-47).

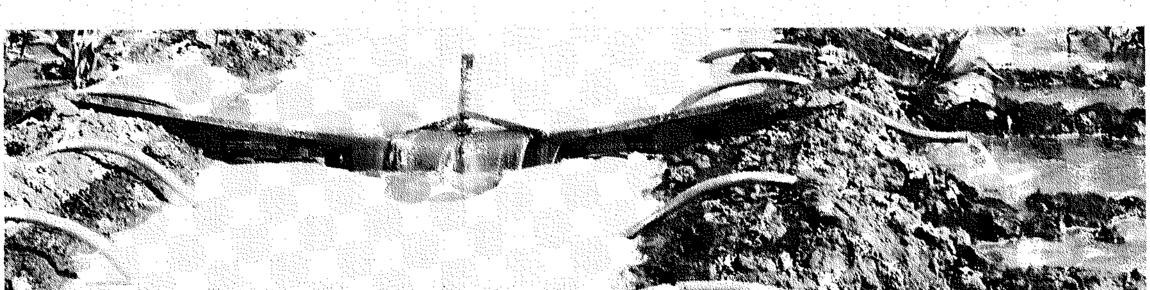
NEB-2144

Figure 3-32.--Combination drop and check.



NEB-2145

Figure 3-33.--Portable plastic check.



OKLA-11150

Figure 3-34.--Portable canvas check.

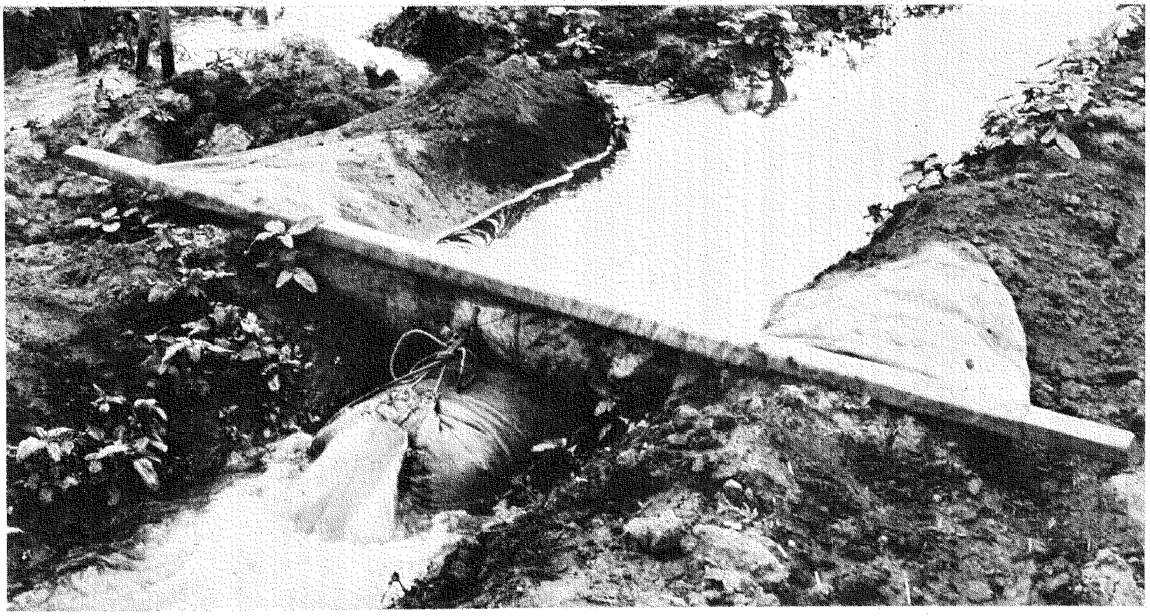


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Figure 3-35.--Canvas check with adjustable sack outlet.

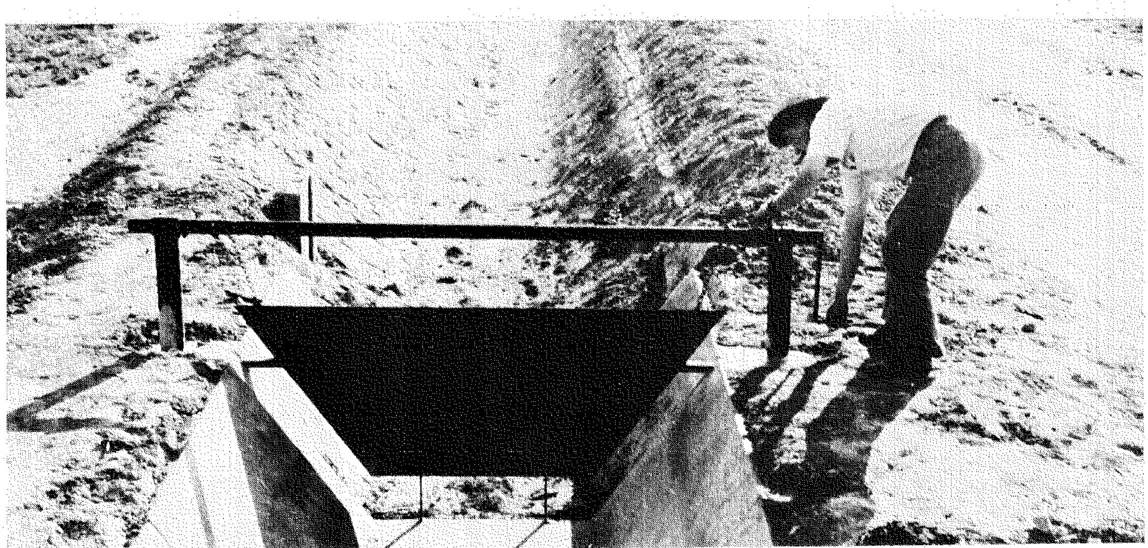

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Figure 3-36.--Metal windless check.

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Figure 3-37.--Adjustable metal check in a lined ditch.

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Figure 3-38.--Permanent concrete check.

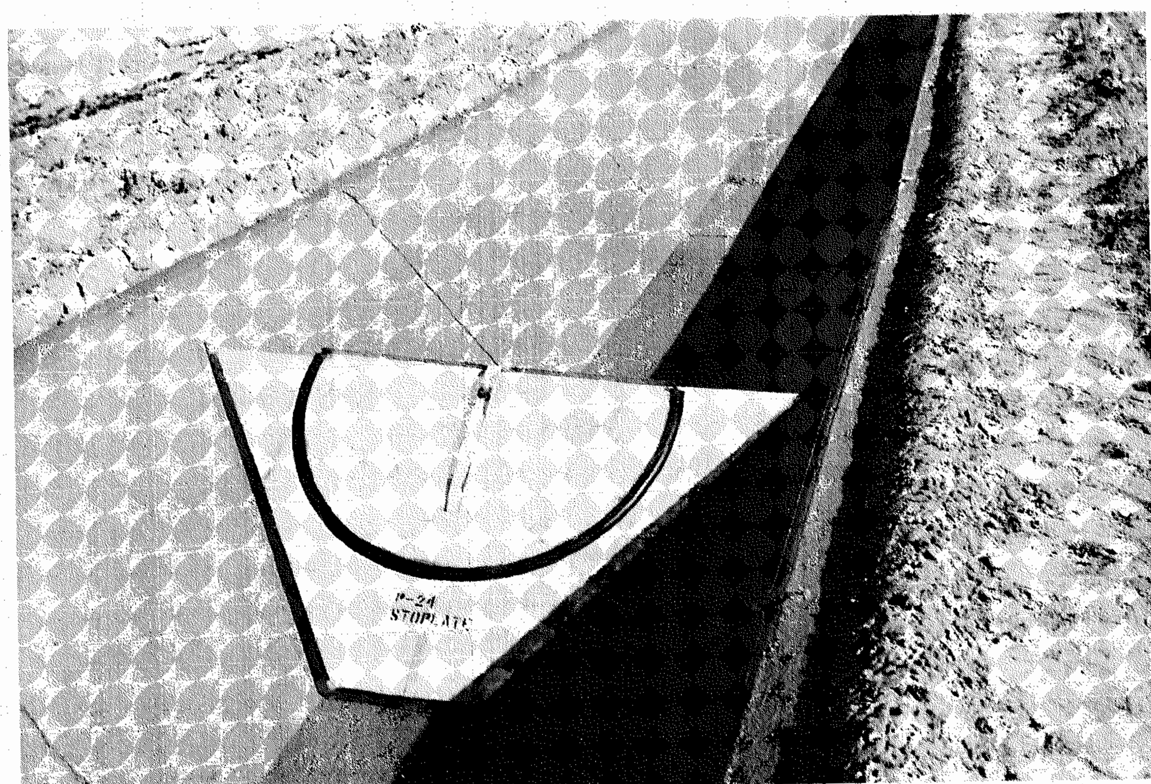


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Figure 3-39.--Installing a metal check.

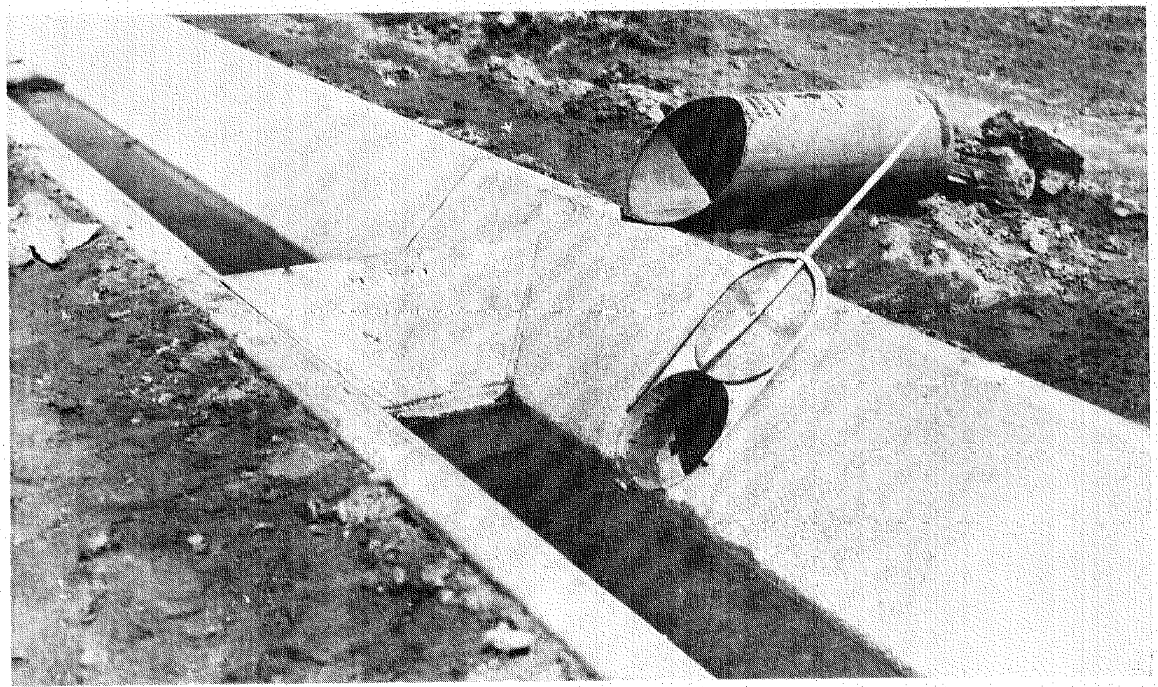

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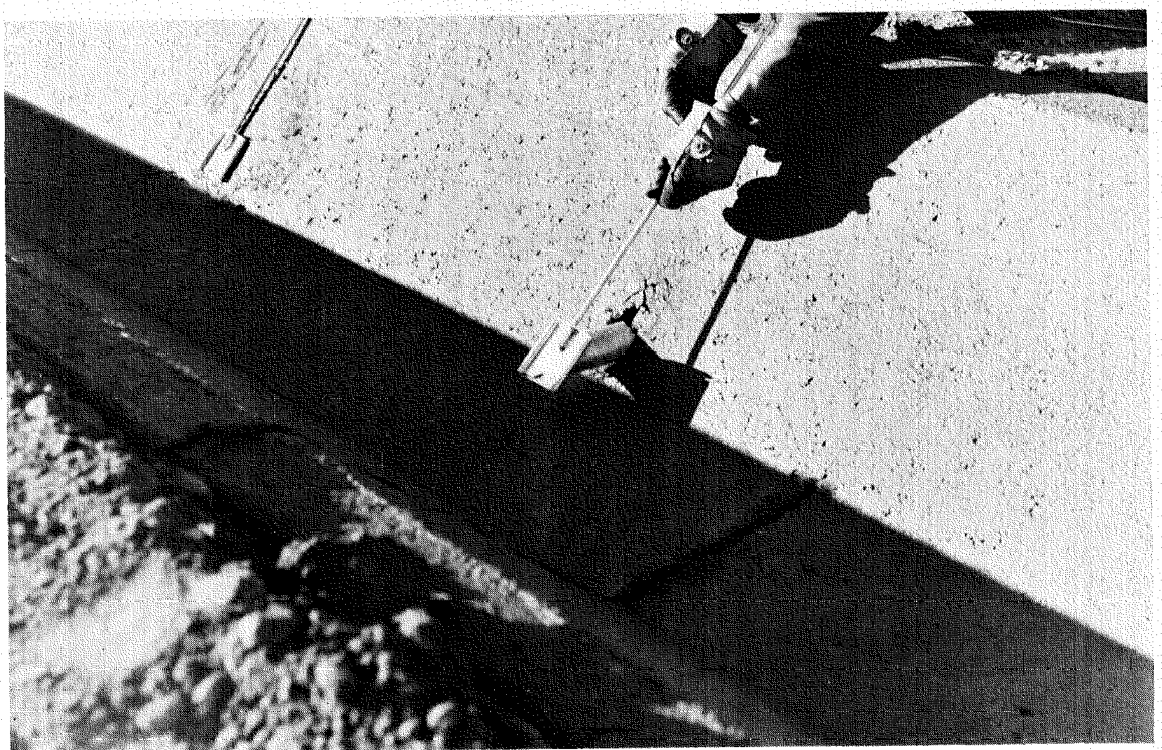
Figure 3-40.--Metal-pipe turnout in a lined ditch.

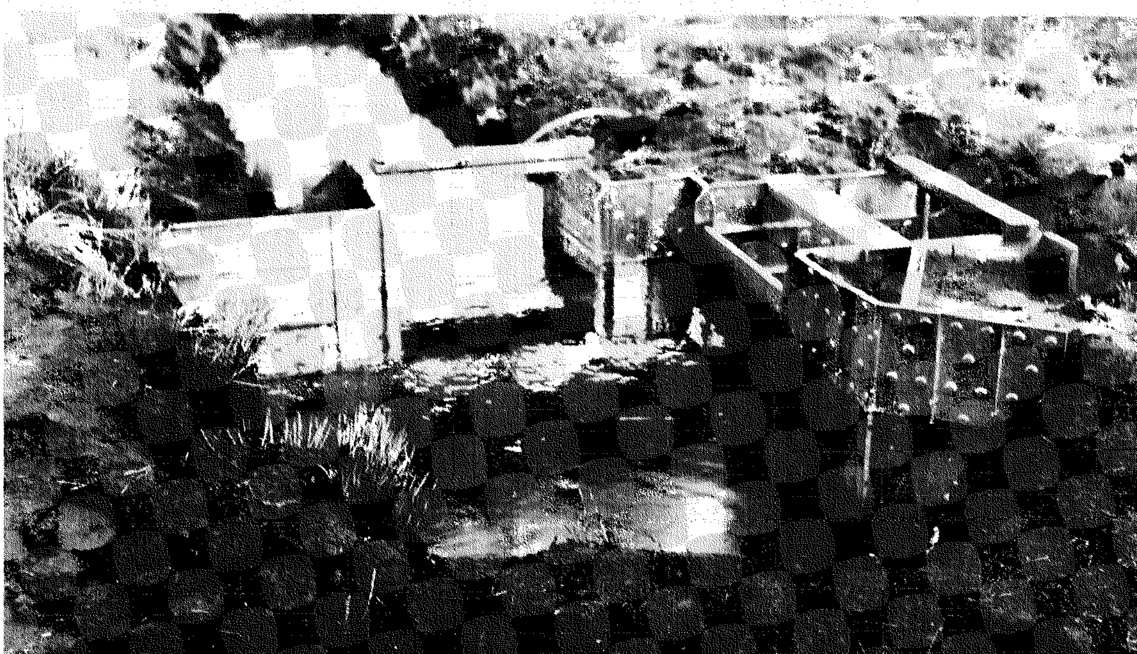


COLO-11264

Figure 3-41.--Two-inch gate turnout.

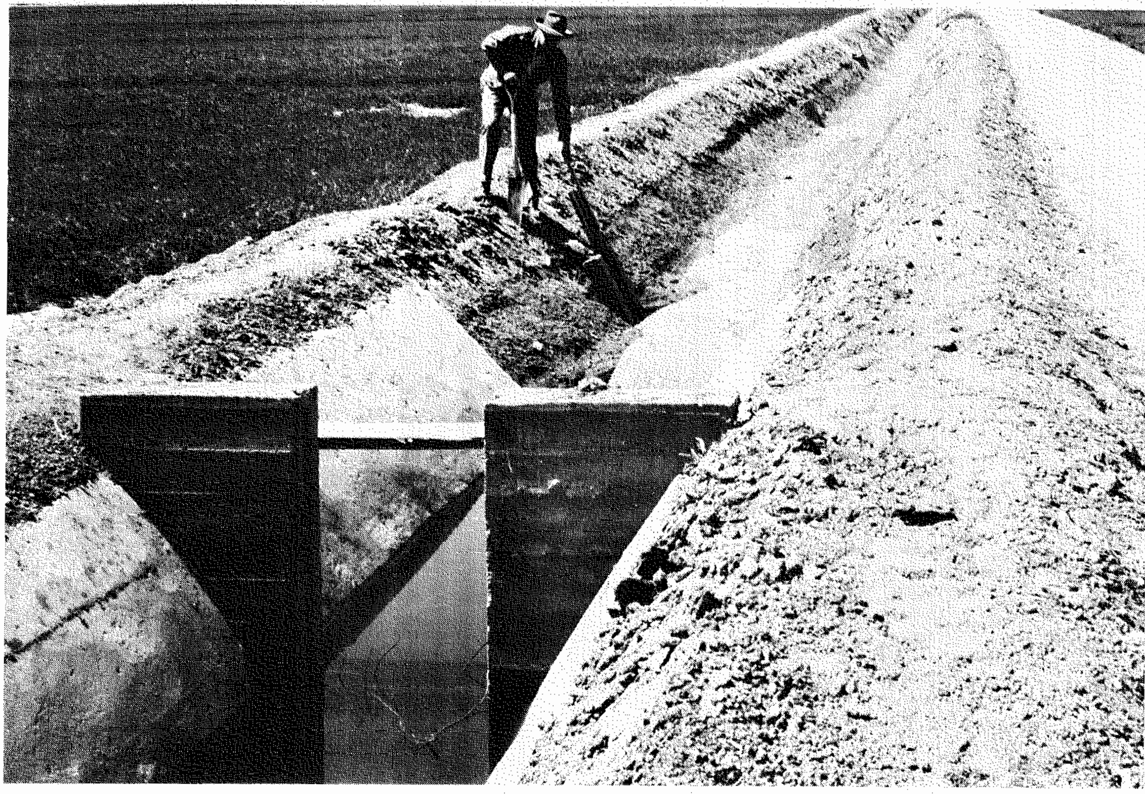
WYO-10166

Figure 3-42.--Concrete-block turnout in a lined ditch.



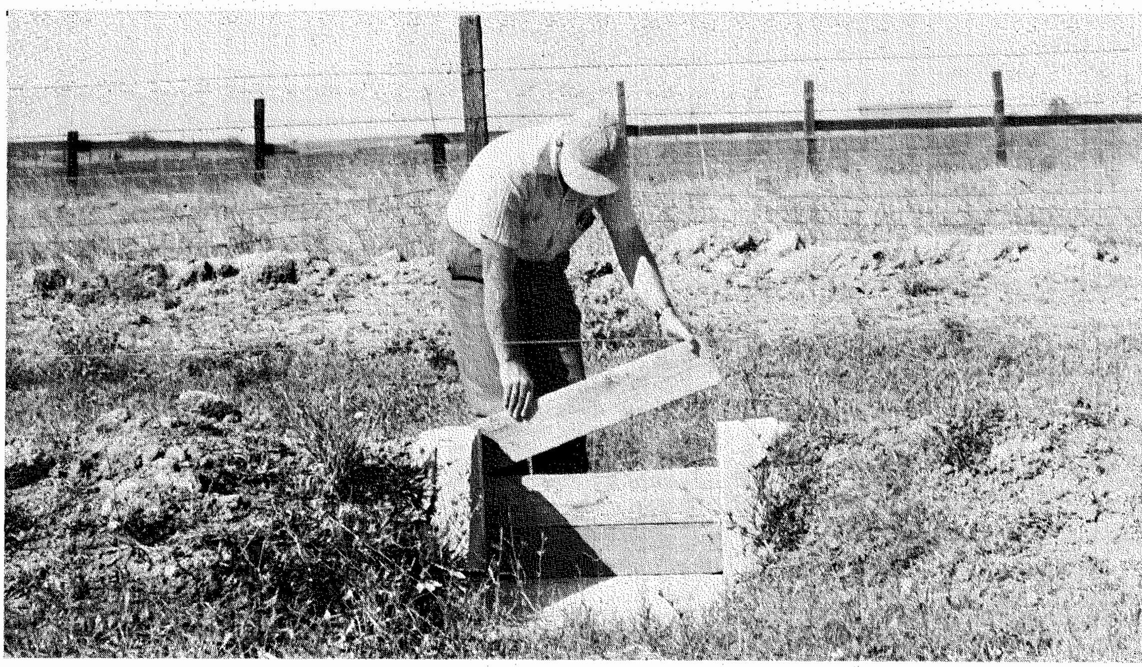
NEB-2146

Figure 3-43.--Metal turnout.



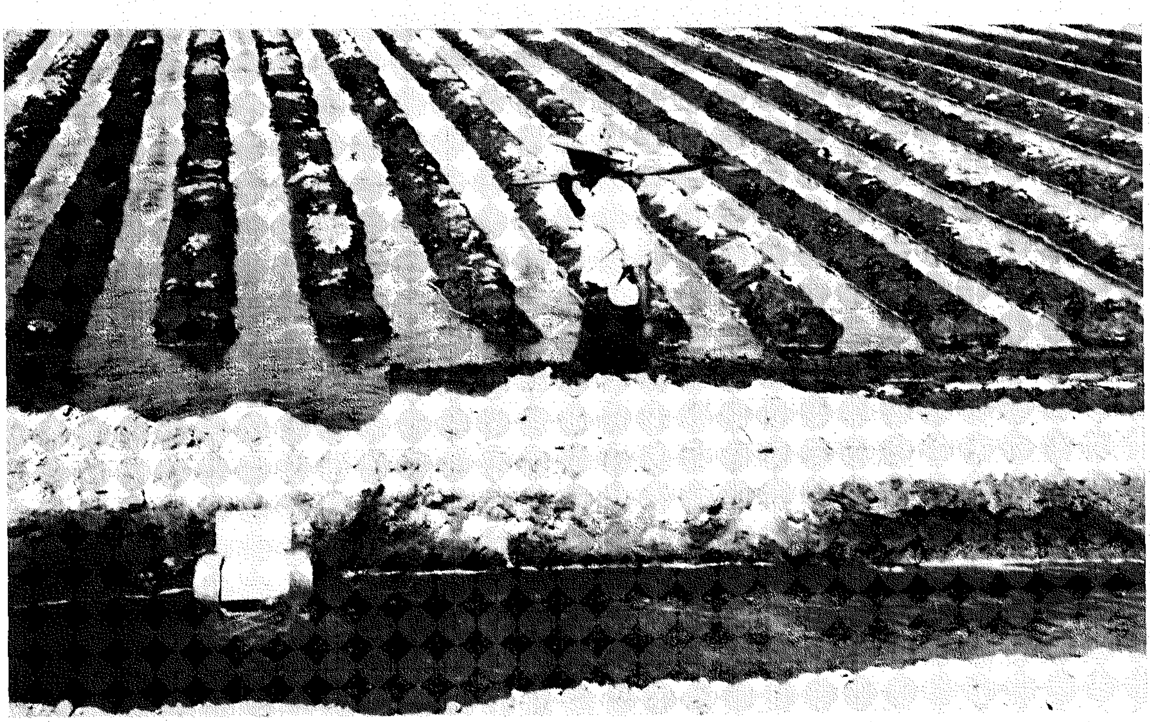
TEX-42645

Figure 3-44.--Turnout boxes in background.



CAL-7344

Figure 3-45.--Concrete turnout with a flashboard gate.



TEX-42667

Figure 3-46.--Concrete-pipe turnout.

IDA-45359

Figure 3-47.--Installing a concrete-pipe turnout.

Concrete- or metal-pipe turnouts must be long enough to extend through the ditch bank. They should be equipped with an antiseep collar and a slide gate. In lined ditches turnouts should be located carefully and be installed at the time the ditch is lined.

Siphon Tubes.--Siphon tubes are small curved pipes that deliver water over the head-ditch bank to corrugations, furrows, and borders (figs. 3-48 and 3-49). Water flows through the tube by the force of atmospheric pressure on the water in the ditch. One end of the tube is placed in the ditch and the other end outside the ditch on the ground surface, which must be lower than the water level in the ditch. The tube must be completely filled for flow to start.

Plastic, metal, or rubber siphon tubes are available commercially. They come in many sizes, having a flow capacity from as little as 1 gallon per minute to more than 1,000 gallons per minute. Capacity varies with tube size and the head on the siphon. Often two or more small tubes are used for each furrow until the water reaches the lower end, then one (or more) is removed to cut back the stream. Flow through siphon tubes can be regulated by controlling the orifice at the outlet or by changing the head.

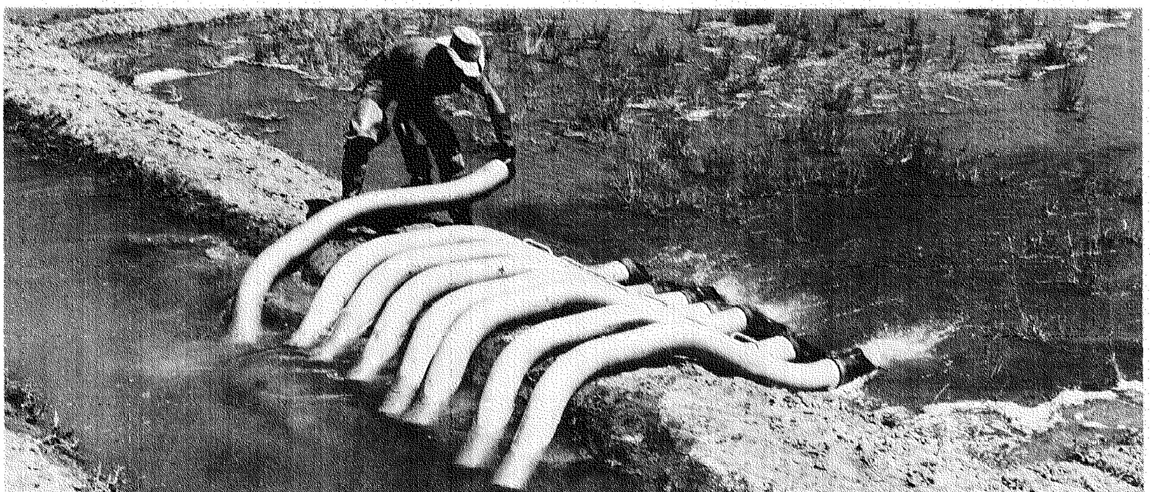
Large siphon tubes, 4 to 8 inches in diameter and 5 to 12 feet long, can be used in place of turnouts. Siphon tubes are used because they can be moved, thus reducing cost of material, but the cost of labor for moving and priming is increased. Another advantage is that ditches are open for cleaning. Siphon tubes are particularly suited to taking water out of a raised ditch. One great difficulty in using large tubes is priming. It is possible to obtain large siphons with adjustable gates on the discharge end, which can be primed by pumping air out of the tubes with a pump on the valve at the top (fig. 3-50).

Gated Pipe.--Gated pipe is portable metal pipe, usually aluminum, with a number of small gates along one side through which water can be run into corrugations, furrows, or borders (figs. 3-51 and 3-52). The pipe can be furnished with gates spaced to match furrow spacing, and the gates can be adjusted to control flow into the furrows. The gates provide positive control and are particularly good if cutback streams are required. The pipe is made in light-weight sections, usually 4 to 12 inches in diameter, that are coupled together easily.

Gated pipe can be used in place of a head ditch at the top of a field or it can be used in conjunction with the head ditch. It is well suited to use in place of an intermediate head ditch on fields too long to be irrigated in one length of run. This permits cultivation through several lengths of run since the pipe can be uncoupled and laid parallel to the rows or be removed from the field during cultivation. Gated pipe is used especially to deliver water to benches and cross-slope or contour furrows. It also provides good control of water on slopes too steep for effective distribution from an open ditch.

TEX-49881

Figure 3-48.--Two-inch siphon tubes irrigating furrows.

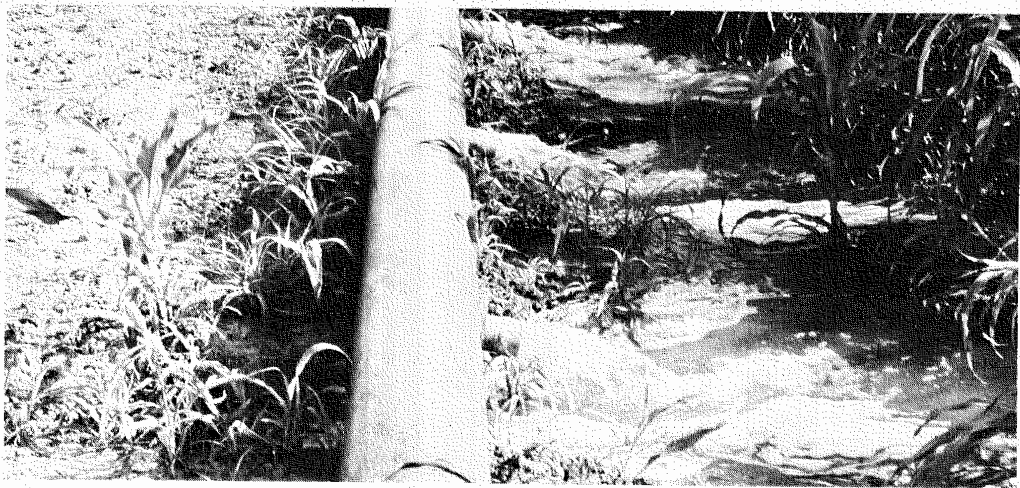


COLO-11149

Figure 3-49.--Eight-inch siphon tubes irrigating a border.

Bn-29651

Figure 3-50.--Large metal siphon and pump for priming.

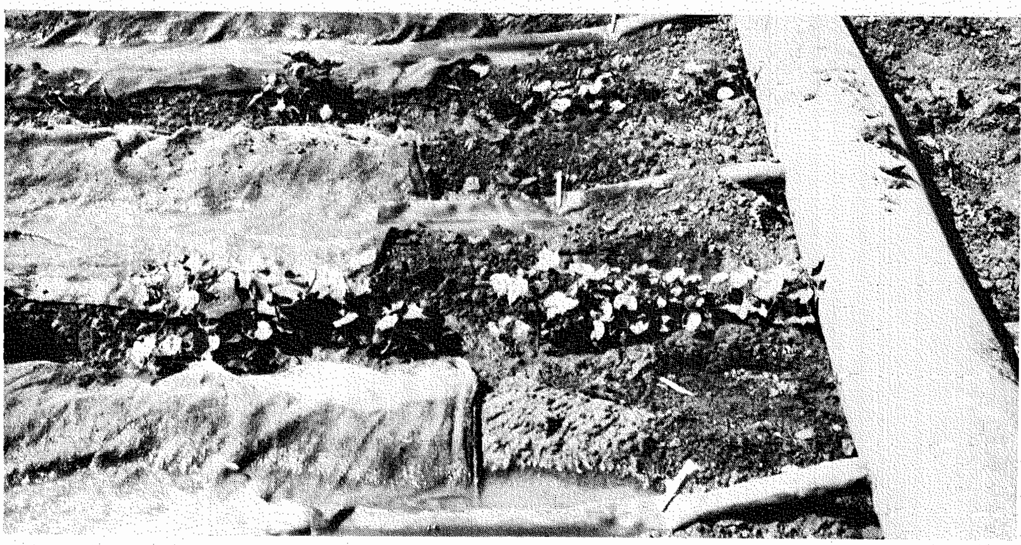


NEB-2148

Figure 3-51.--Gated pipe for furrow irrigation of corn.

NEB-2149

Figure 3-52.--Closeup of gate in pipe.



OKLA-11898

Figure 3-53.--Flexible gated pipe; sacks prevent erosion and clothespins regulate flow.

Flexible Gated Pipe.--Flexible gated pipe, sometimes known as surface hose or lay-flat tubing, can be made of plastic, rubber, or canvas with outlet tubes spaced according to the furrow spacing (fig. 3-53). There are various means of adjusting flow through the outlet tubes, for example, adjustable clamps. Flexible pipe or hose can be rolled up for easy moving and storage and can be used in the same places as gated metal pipe. Initial cost is less than that for gated metal pipe. Plastic and canvas pipes have the disadvantage of short life and must be handled carefully. Rubber pipe has a longer life but is heavy.

Spiles.--Spiles are pipes, 1 to 4 inches in diameter, used to distribute water from a ditch into corrugations or furrows. They are set permanently in the bank of the head ditch and must be long enough to extend through the bank. They are used at places where the head ditch is nearly flat. The water elevation in each ditch section can then be controlled by a check. It should be high enough above the center of the spile opening to deliver the maximum nonerosive stream until the water reaches the end of the run. Then the water can be lowered to a point that delivers the cutback stream through the spiles.

## Pipelines

Irrigation pipelines are a means of conveying water through closed conduits. Since pipelines are costly, careful planning is required for location, capacity requirement, selecting the best material, and good construction practices. Irrigation pipelines can be used for the same purposes or in place of open channels.

Pipelines can be either on the surface or underground. Portable surface pipe has an advantage over underground pipe in that it can be moved and used in more than one location, but it has a disadvantage in the labor required to move it. Underground lines are plain concrete, reinforced concrete, asbestos-cement, steel, wrapped aluminum, fiber, or plastic pipe (fig. 3-54). Surface pipe is made of aluminum, steel, rubber, plastic or canvas. The choice of material depends on the conditions under which the pipe is to be used, cost, and the farmer's personal preference.

Pipe conduits can be used in most places. They are particularly suited to areas where seepage losses are high. Pipe can be used to advantage in places difficult to excavate and to carry water down steep slopes. Pipelines are also good in areas where water supply is limited and losses must be kept to a minimum. Pipelines almost eliminate losses from evaporation and seepage. Weed control and farming operations are easier, and less tillable land is taken up. Maintenance work in general is less than that for open ditches, and water control is easier.

Cost is probably the main limiting factor in using pipe to carry irrigation water. Even though the initial installation cost is higher than that for comparable open-ditch systems, the overall annual cost often is less.

Two general kinds of pipeline are used--low pressure and high pressure. Low-pressure pipelines are open to the atmosphere and are usually used with operating heads of less than 20 pounds per square inch. High-pressure pipelines are closed to the atmosphere and are used where operating heads of more than 20 psi are required. Valves are used in lieu of open vents and stands.

## Low-Pressure Pipelines

Low-pressure pipelines are used primarily with surface irrigation methods. They can be permanent, semiportable, or portable. Permanent farm systems usually consist of buried supply and distribution lines. In semiportable systems buried pipe is used for field supply lines, and some kind of quick-coupling metal pipe or flexible pipe is laid on the ground surface to distribute the water. A fully portable system uses metal or flexible surface pipe for both field supply and distribution.

Concrete generally is used for low-pressure buried lines, but steel, wrapped aluminum, fiber, asbestos-cement, or plastic pipe can be used. Concrete pipelines are either precast (fig. 3-55) or cast in place (figs. 3-56 and 3-57). Concrete pipe is made with tongue and grooved joints, which are sealed with rubber gaskets or filled with cement mortar.

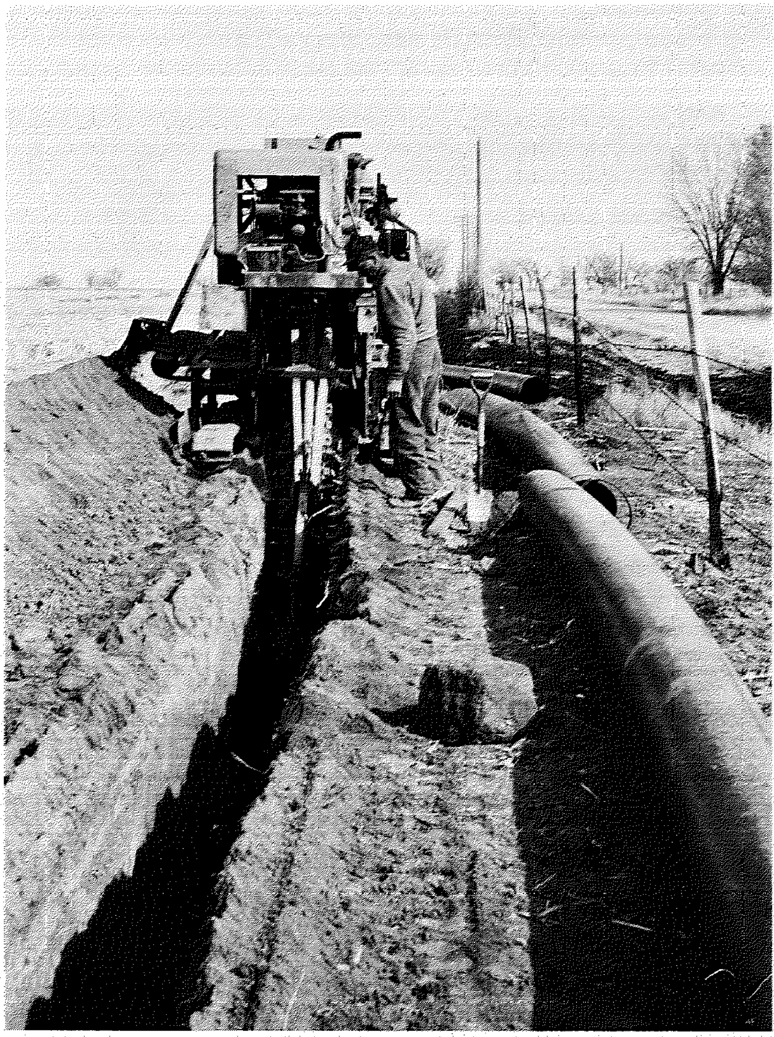
It is very important that a pipeline be large enough to convey the flow needed in different fields under present and future conditions. It must be large enough to supply the water required during the period of peak crop use even though this full capacity may be needed in only a small part of the total irrigating season.

Specialized structures are needed on pipelines to control water and to protect them against damage. Pipelines on sloping land may develop excessive pressure heads that must be controlled by standpipes or regulating valves. Lines fed directly from pumps also must have structures for controlling the maximum pressure automatically.

## High-Pressure Pipelines

High-pressure pipelines generally are used to convey water for sprinkler irrigation. Since sprinklers usually require a pressure of 40 pounds per square inch or more for efficient water distribution, the pipeline must be designed as a high-pressure system to withstand this pressure. The supply line or sprinkler main line may be a permanent buried line or a portable metal surface pipeline. Buried lines cost more to install, but their maintenance and operating costs are lower than those for surface pipe. Buried lines do not interfere with farming operations and are less likely to be damaged by farm machinery and vehicles.

A buried main line may extend from the water source to individual fields, and surface pipe is used for the field main and laterals. This permits moving the field main and laterals to other fields. Or a buried main line can extend into the fields to be the field main and have risers and valves at the location of each lateral line.



COLO-11187

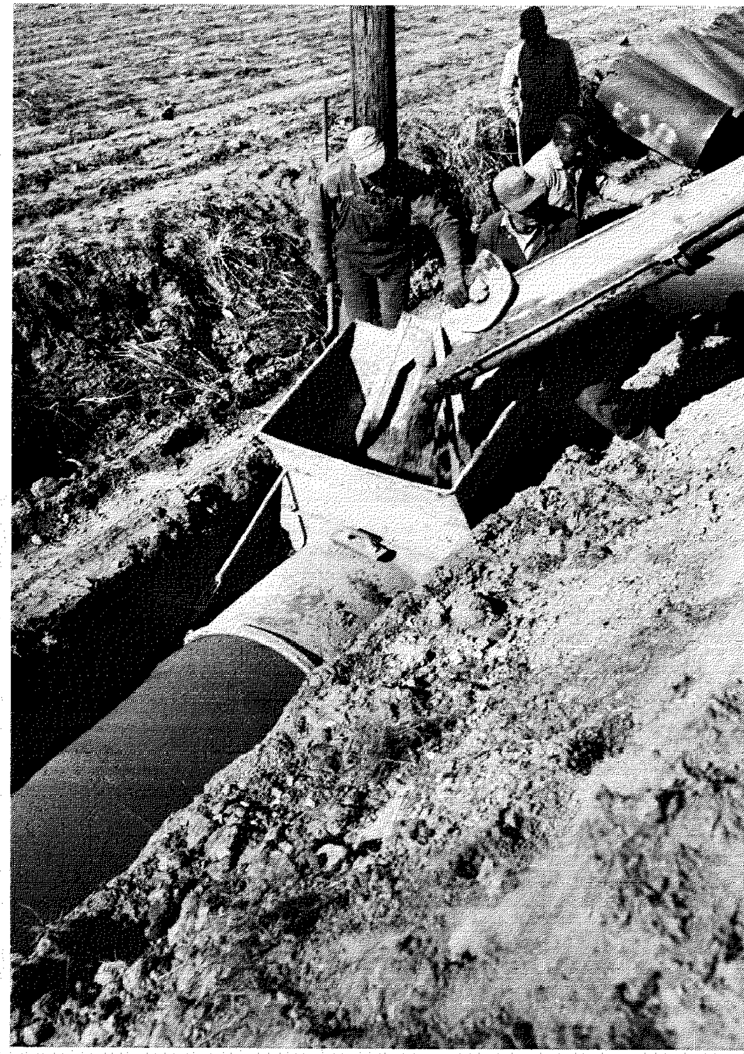
Figure 3-54.--Installing plastic pipeline.

COLO-11172

Figure 3-55.--Installing 15-inch concrete irrigation pipe.

NEB-2151

Figure 3-56.--Removing inside form from concrete pipeline cast in place.



COLO-11263

Figure 3-57.--Pouring concrete pipeline using sheet-metal slip form.

A buried main line is either metal, asbestos-cement, or plastic pipe. Portable surface lines are aluminum pipe in 20-, 30-, or 40-foot lengths with quick couplers, plastic pipe, or hose. If the water is from an open source where debris can collect, trash screens should be installed at the pump inlet. The screens should be fine enough to remove weed seeds and other small particles that may clog sprinkler nozzles. Chapter 11 contains information on selecting and designing sprinkler systems.

## Inlet Structures

An inlet structure is often needed to prevent damage from excessive pressure, to develop the full flow capacity of a pipeline, and to keep trash from entering the pipe. The kind of structure depends on the water source since water enters by gravity flow from a ditch or is pumped into a line from a stream or well.

Pump Stands.--A pump stand is a vertical pipe extending above ground from a buried pipeline (fig. 3-58). It carries flow from the pump into the pipe system and must be large enough to let the air entrained by the high-velocity stream escape.

The stand must be high enough to prevent overflow at the usual operating pressure yet permit overflow at excessive pressure. High pump stands can be capped and vented with a pipe of small diameter (fig. 3-59). To prevent damage from vibration, the pump should be connected to the stand by a flexible coupling. Pump stands are usually used for low-pressure pipelines.

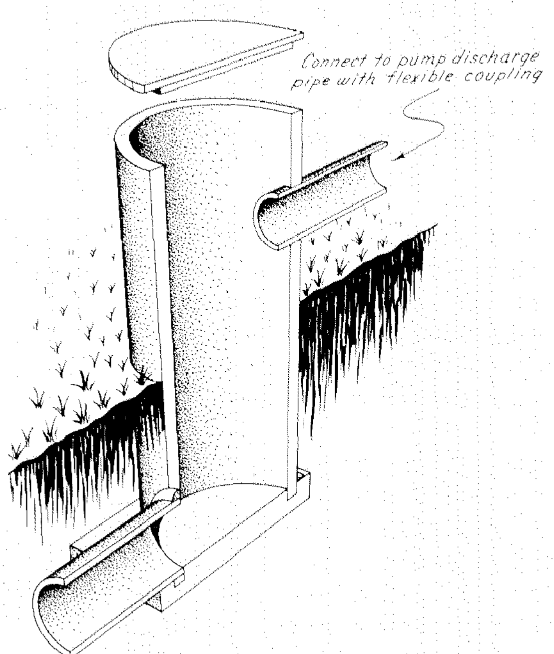



Figure 3-58.--Low-head open stand for concrete pipe.

NEB-2150

Figure 3-59.--Capped high-head steel stand.

Gravity Inlets.--For pipelines into which water flows by gravity from an open ditch, a gravity-inlet structure (fig. 3-60) that may include a sand trap, debris screen, or trash rack is needed to develop full pipe flow and keep trash out. The top should be covered to keep trash from blowing in and to prevent accidents.

Sand Traps.--A sand trap is a settling basin used to remove sand or silt carried in irrigation water. It can be built into the pump stand or gravity inlet by setting the bottom of the stand some distance below the bottom of the pipeline (fig. 3-61). The stand should be large enough to keep water velocity low and to permit cleaning.

Debris Screens.--Debris screens are used to remove trash, weed seeds, and other debris carried in irrigation water from open ditches, rivers, or lakes. This is especially important if sprinklers are used. If water is pumped into a pipeline from an open source, the end of the suction pipe can be fitted with a fine screen. Water entering by gravity flow should fall through a fine screen, which must be cleaned frequently. A horizontal self-cleaning screen can be installed if the water source is high enough to provide a drop of 1 foot or more at the pipe inlet (figs. 3-62 and 3-63). The falling water washes the trash to one side or completely off the screen.

## Vents

Vents to relieve pressure and release air are used at all high points of a pipeline, at points where its slope sharply increases in the direction of flow, at sharp turns, at the end, and directly below any structure that entrains air in the flowing water. All vents must extend above the hydraulic grade line to prevent overflow when the line is operating normally. By allowing air to escape, vents permit a pipeline to carry more water, relieve surges and prevent damage to the line when gates or valves are opened or closed, and keep the line from collapsing when it is drained.

Straight Vents.--A straight vent is a pipe extending straight up from a buried pipeline. The diameter of the vent is the same as the diameter of the pipeline. Generally a straight vent is placed on top a hole cut in the line after the line is laid. The maximum height must not exceed the safe working head of the pipeline plus freeboard. An anchor should be cast around the pipe under the stand to maintain alinement.

Capped Vents.--A capped vent differs from a straight vent in that at or near the ground surface it is capped over and a smaller pipe extends through the cap to the necessary height, generally 2 feet above the maximum hydraulic gradient. The area of the small pipe should not be less than one-sixtieth of the area of the main pipe and the diameter should never be less than 2 inches. The cap should have a minimum height of two diameters above the crown of the pipeline. The smaller pipe is generally made of steel, sheet metal, or asbestos cement. Capped vents can be used in place of straight vents but commonly are used if

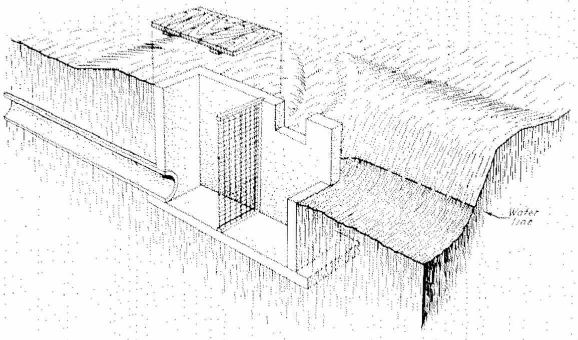



Figure 3-60.--Gravity inlet for buried low-pressure pipeline.

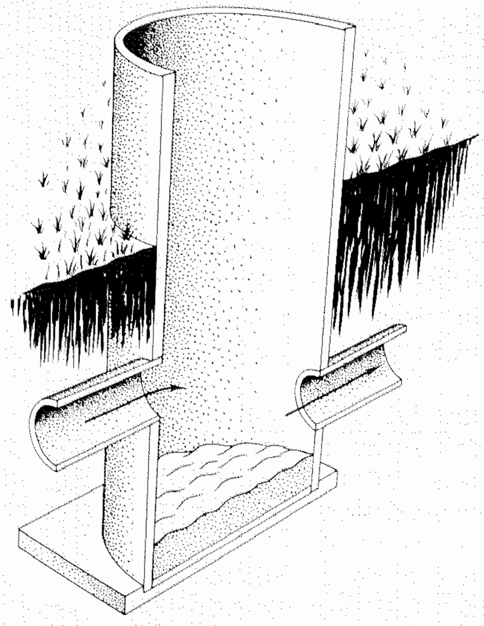


Figure 3-61.--Typical concrete-pipe sand trap.

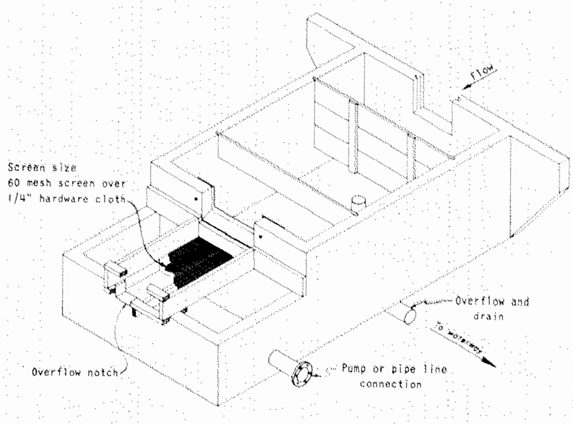
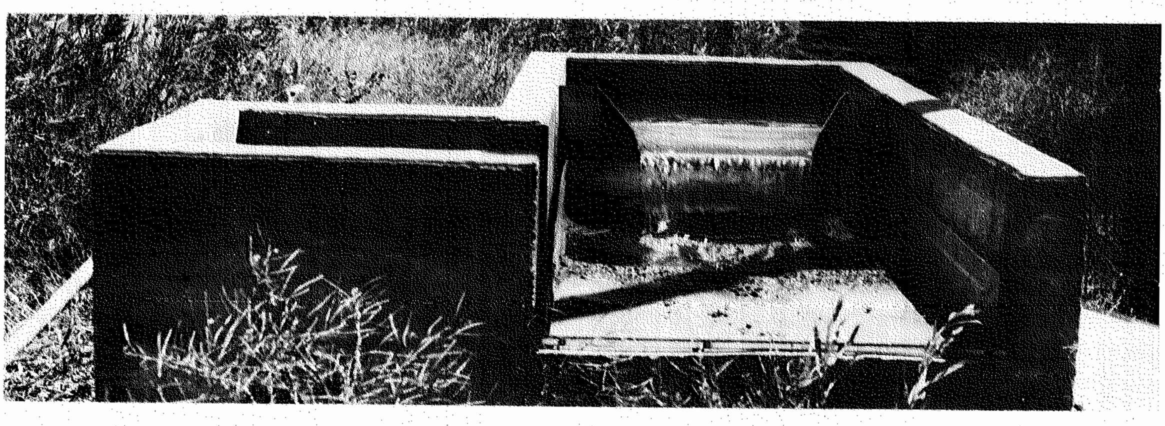



Figure 3-62.--Typical trash screen.



WN-90249

Figure 3-63.--Desilting box and trash screen.

the hydraulic gradient is more than 8 feet above ground surface (figs. 3-64 and 3-65).

Air-Release Valve Vents.--These vents are capped vents that have an air-release valve in the smaller pipe at some convenient height above the ground. They are used in places where otherwise extremely high vent pipes would be required (fig. 3-66). When air enters the valve, a floating ball drops, opening the valve until the water rises again. The valve permits air to escape or enter but does not allow water to pass. If the valve sticks, a gate valve can be placed immediately below the release valve for use until repairs can be made.

Control Structures

Different control structures are used on irrigation pipelines to regulate the flow into branching lines, to remove entrained air, and to prevent momentary high pressures from damaging the pipeline.

Gate Stands.--Gate stands are similar to other types of stands but must be large enough to accommodate the gates to be used and to permit access for maintenance and repairs. They are used to control flow into laterals or to increase pressure upstream. The increase in pressure may be needed to force water from hydrants upstream. If laterals take off at the stand, the gates can be opened or closed to divert water as desired (fig. 3-67). Gate stands also prevent excessive pressure and act as air vents and surge chambers.

A gate stand may be concrete pipe or a concrete box, and a box stand is an excellent structure in which to install gates. Gates are usually set on the outlets from the stand so that water pressure in the stand closes the gates rather than holding them open.

It is possible to substitute line gates in each lateral line for the gates inside a stand. This is usually done if high stands are required. Line gates can be operated from the ground instead of from the top of the stand. They are not desirable if the structure must also serve as a sand trap.

Overflow Stands.--Overflow stands are generally two concrete pipe stands joined together--one at the pipeline elevation in which a gate is installed and the other at the elevation of the overpour lip. The upstream stand must be large enough to accommodate the gates to be used and to permit access for maintenance and repairs. Overflow stands (figs. 3-68 and 3-69) serve as both checks and drop structures in addition to the usual functions of a stand. They are not needed on flat areas or on very slight slopes but are used in areas where slopes are so great that excessive pressure can be developed downstream.

As checks, they regulate pressure to maintain constant upstream flow from hydrants or into laterals. As drop structures, they cause a drop on the hydraulic gradient, thus limiting pipeline pressure. The gate valve is open if upstream pressure is not required. If diversion or

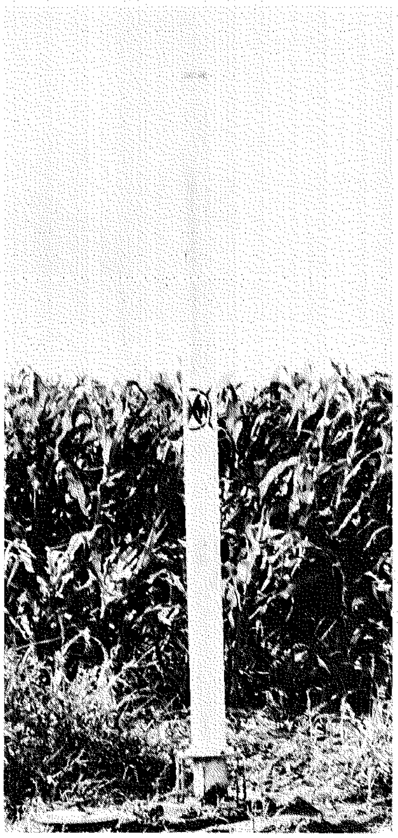


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Figure 3-64.--Typical capped vent.

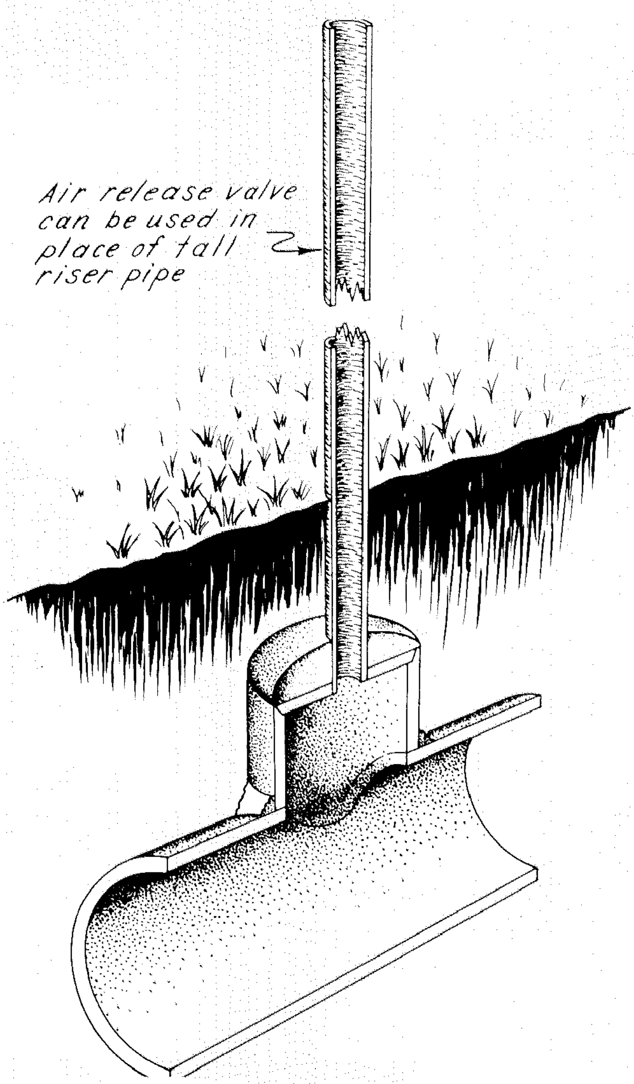


Figure 3-65.--Section of a capped vent.

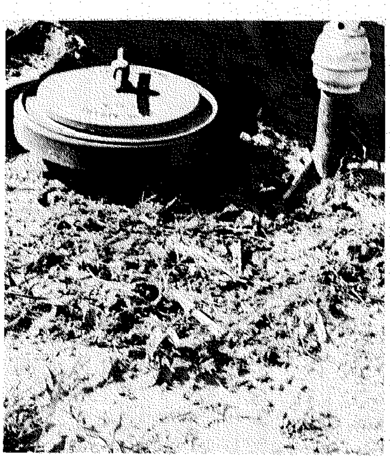

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Figure 3-66.--Closeup of air-release valve on right and alfalfa valve on left.

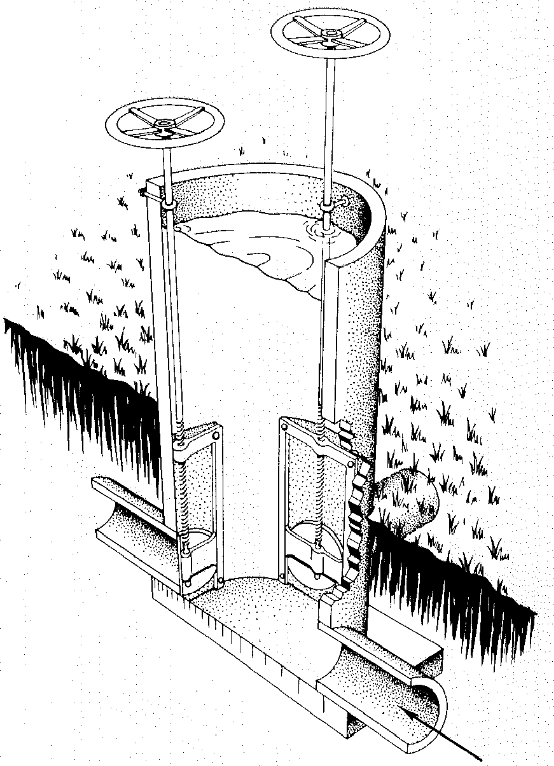

Figure 3-67.--Section of a concrete-pipe gate stand used to control flow into two laterals.

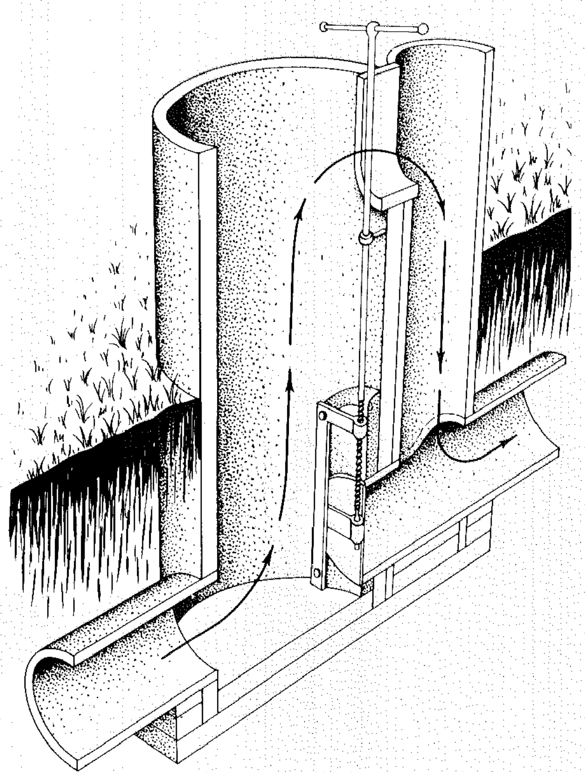

Figure 3-68.--Section of concrete-pipe overflow stand.

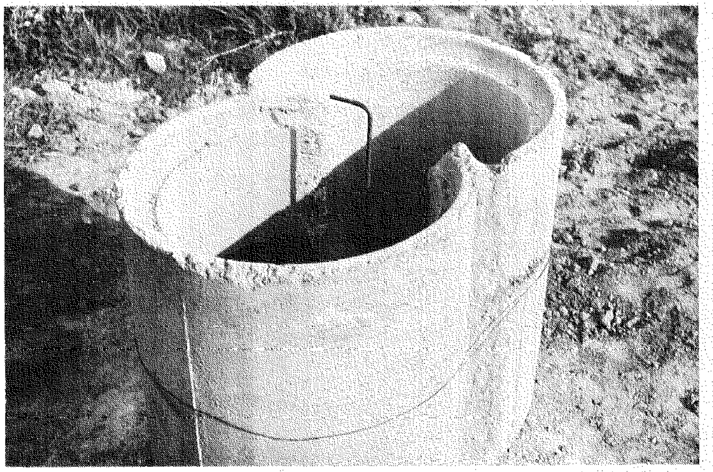

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Figure 3-69.--Concrete-pipe overflow stand.

discharge of hydrants immediately upstream is required, the gate valve is closed enough to keep the head upstream at about the overflow crest but with little or no overflow.

Float-Valve Stands.--Float-valve stands are similar to other stands except that a float valve is attached to the end of the pipe through which water enters the stand (fig. 3-70). The valve controls pressure in the reach of pipe immediately downstream from it. It releases into the stand only as much water as hydrants farther downstream are open to take. Thus, by opening and closing, the valve maintains a nearly constant water level in the stand, which is connected directly to the line or lines through which water flows downstream. When the lower outlets are closed, the float valve automatically closes and prevents excessive pressure from developing at the lower end.

Float-valve stands are useful on steep slopes and are usually installed at intervals of about 10 feet of drop in the line. They are especially good if a line is served directly from storage since the water can be controlled completely from the lower end of the line. Float-valve stands eliminate the need for many high overflow stands on steep slopes. They are usually made of reinforced concrete pipe having a minimum diameter of 30 inches. Generally about 2 feet of freeboard is desired and 1 foot is the minimum.

## Outlets

Some type of outlet structure or hydrant is necessary in pipelines to deliver water to the land or into some distributing device. Hydrants are risers built from vertical sections of pipe, which are saddled over openings in the pipeline and permanently attached to it with a waterproof joint. Some kind of valve or gate is installed in the riser to regulate discharge through the hydrant.

Alfalfa Valves.--An alfalfa valve is a screw valve grouted to the top of a pipe riser (fig. 3-71). A handle and cap plate is attached to a threaded rod that moves up or down as the handle is turned. When the valve is closed, the cap plate fits the circular edge of the valve case to make it watertight. When the plate is lifted by turning the handle, water is released from all sides of the valve.

Alfalfa valves are used to distribute water directly to border strips, basins, or ditches. The valve top should be 3 to 4 inches below the ground surface to minimize interference with farming operations and to reduce erosion from the irrigation stream. Alfalfa valves can be fitted with hydrants for connecting to surface pipes (fig. 3-72).

Orchard Valves.--Orchard valves (figs. 3-73 and 3-74) are similar to alfalfa valves but have a smaller flow capacity and are so designed that they can be placed at the top of the riser, at the bottom, or at almost any point between. The preferred location is near the top.

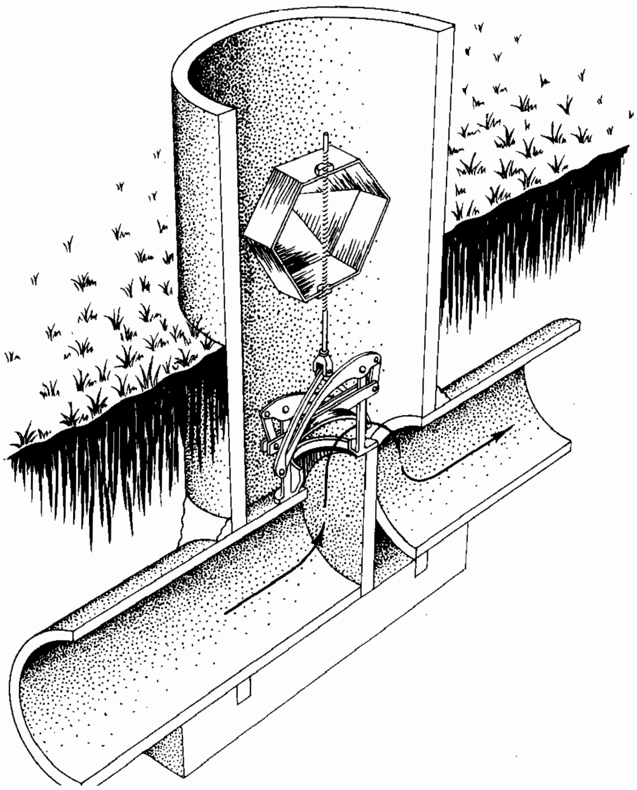

Figure 3-70.--Section of a float-valve stand.

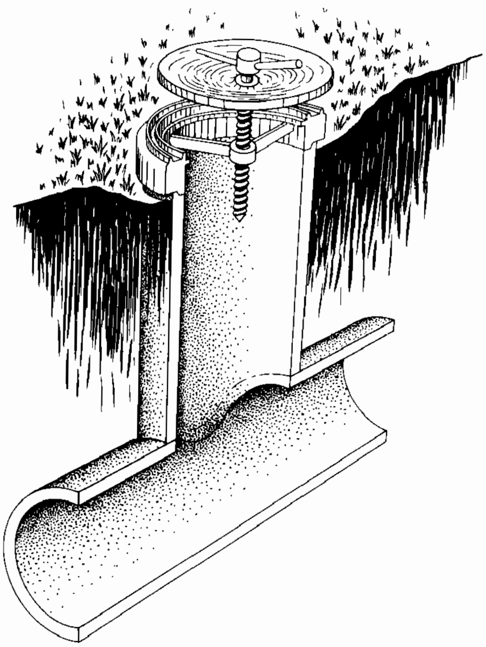

Figure 3-71.--Section of alfalfa valve mounted on concrete pipe.

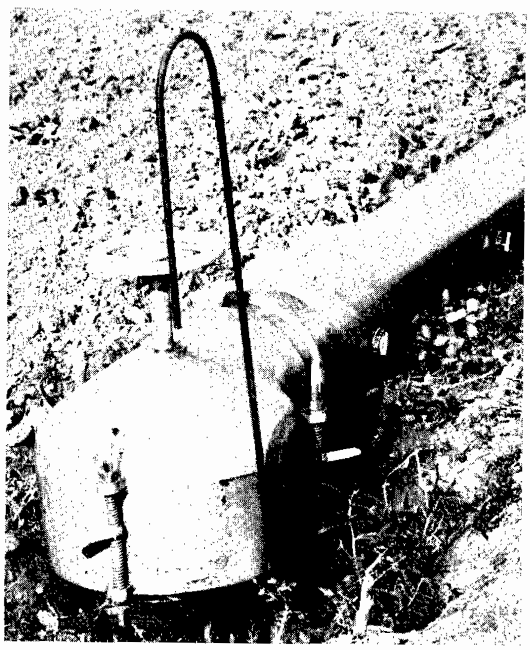

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Figure 3-72.--Hydrant attached to alfalfa valve for gated pipe.

Orchard valves are used instead of alfalfa valves if a smaller flow is acceptable. Because of their lower capacity, they are less likely to cause scour around the riser, the top of which should be level with the ground surface. It is also possible to place an additional length of pipe that has an opening on one side above the ground line to direct flow from the valve. Sheet metal stands and hydrants can also be fitted to orchard valves to deliver water into surface pipe or ditches.

Open-Pot Outlets.--In open-pot outlets the riser extends above the ground surface far enough for two or more slide-gate tubes to be installed close to the ground line. An orchard valve is placed below the slide gates (fig. 3-75). This kind of outlet distributes water through the gates to furrows and is used principally in orchard irrigation systems.

Orchard valves regulate flow into the pot, and the slide gates regulate flow into individual furrows. Good control can be had by adjusting the orchard valve to keep the water surface only an inch or two above the slide gates. The slide gates are placed inside the pot at ground elevation to minimize erosion of the adjacent soil. Size of the pot depends on the number and size of slide gates to be used. If line pressure is low enough that the pot will not overflow, an orchard valve is not needed in the riser. Then all the flow is controlled at the slide gates.

Capped Risers or Pot Outlets.--In these outlets (fig. 3-76) the top of the pot is capped, the slide gates are installed on the outside of the riser, and an orchard valve is not used. Flow is controlled by adjusting line pressure and by the slide gates. Capped-pot outlets are used only in irrigating orchards and permanent crops where small flows are distributed to the individual furrows.

The main advantage of capped-pot outlets is that leaves cannot fall into the pot and clog the slide gates and that an orchard valve is not needed. The disadvantages are less control of flow and that, because of the pressure, the jet of water from the slide gate may erode the adjacent soil. Special screw valves are available for use in place of the slide gates. These valves are designed to break the force of the jet and give a quiet nonerosive flow. Capped-pot outlets can be used where the pressure will not be more than 1 or 2 feet above the ground surface.

Surface-Pipe Outlets.--Surface-pipe outlets are risers extending above ground that are equipped with tubes or connections for attaching surface pipe to pipelines without using hydrants. Water for irrigating furrow crops is generally distributed by surface pipe. The risers must be high enough to produce the required pressure in the surface pipe. If the pressure in the pipeline is more than that required for the surface pipe, the outlet can be equipped with orchard valves to keep the riser from overflowing. In some low-pressure installations the connecting tube is equipped with a gate or the slide gates at the individual furrows are used as the controls.

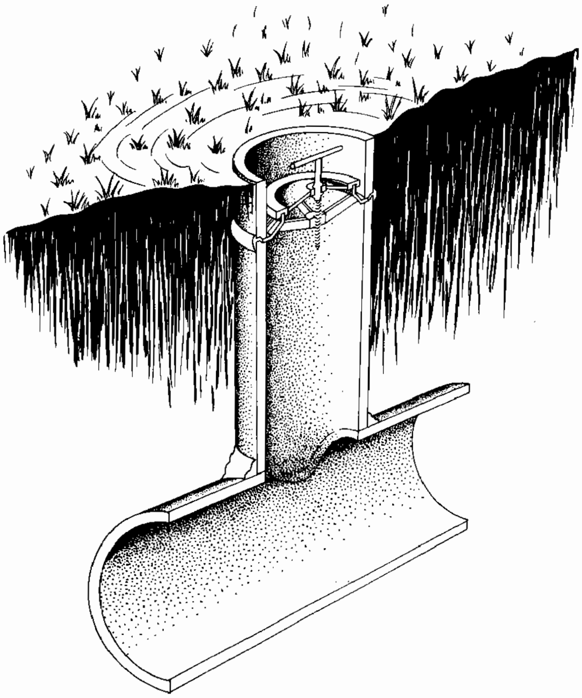

Figure 3-73.--Section of an orchard valve.

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Figure 3-74.--Orchard valve.

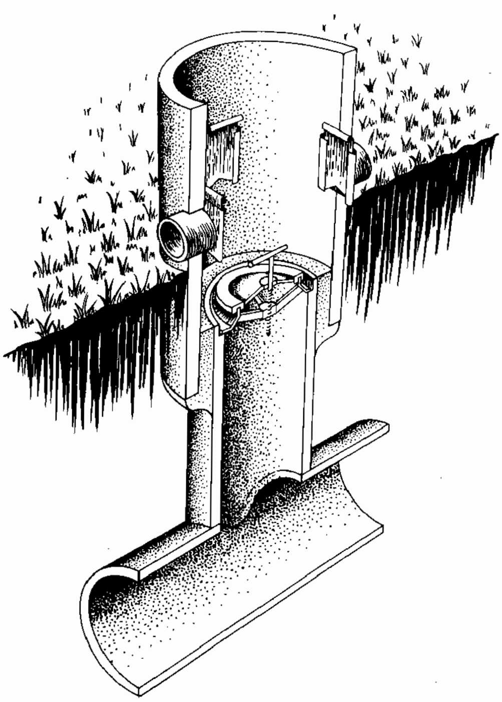

Figure 3-75.--Open-pot outlet with an orchard valve and slide-gate control.

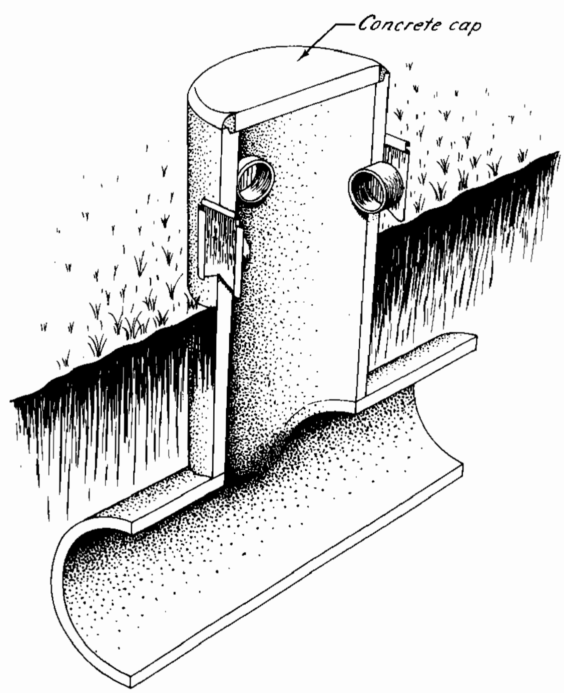


Figure 3-76.--Section of capped riser or pot outlet.

## Water Disposal

The design of a farm irrigation system should provide facilities of adequate capacity to remove excess water from the irrigated land promptly and safely. The excess water may be waste from irrigation, surface runoff from rainfall, or excess percolation of either irrigation water or rainfall. It may also include leakage or seepage from parts of the conveyance system.

Some waste can be expected in using any of the graded-surface irrigation methods, but it can be kept to a minimum by good design and management. There is always the possibility of accidentally releasing excess irrigation water that must be controlled and removed. If you are planning to apply additional water for leaching or rice culture, you must also plan proper disposal facilities.

Storm runoff must be removed to protect the land, the irrigation system, and crop investment. This may require special erosion control measures or modifications in the design or layout of an irrigation system. Excess percolation of either irrigation water or rainfall may lead to a high water table that restricts root growth or promotes a saline or alkali condition. Seepage from canals, reservoirs, and sumps may waterlog adjacent land, and tile or open drains may be necessary to control the water table if natural internal drainage is not adequate.

To determine the kind of disposal needed, make a survey of the topography, kinds of soil, water table, and water sources. You must determine the areas from which water must be removed, the amount to be removed, the best way to remove it, and the points of disposal. Then design the water-disposal system according to approved standards.

### Surface-Water Disposal

Excess surface water from irrigation waste or storm runoff must be removed for good plant growth. Generally open ditches or grassed waterways are used. Their location and capacity depend on the application method, rainfall amount and intensity, level of protection desired, topography, erodibility and internal drainage of the soils, as well as adequacy of the natural drains.

### Effect of Irrigation Method

The application method particularly affects layout of the disposal system. Tail or waste ditches are needed at the lower end of furrows and borders to collect and remove excess surface water. For the contour-furrow method, grassed waterways are needed to pick up the water discharged from each furrow. For the contour-levee method, a waste ditch running downslope and connecting each leveed area is needed to remove waste water. On land leveled for contour benches, waterways drain the benches and generally some structures are needed to carry water between benches. For sprinkler irrigation, excess rainfall can be controlled and disposed of by terraces and diversions leading to grass waterways. On flat land where there is no erosion hazard, shallow surface drains are used. In subirrigation systems, runoff water is disposed of through water-control structures placed in open ditches or tile drains. Pickup ditches must be provided to keep water from flowing directly from furrows or borders into irrigation head ditches.

### Design Considerations

Tail ditches generally are shallow open drains large enough to carry away irrigation waste water and storm-water runoff. Storm runoff generally governs capacity. Grade should be as uniform as possible. Design the cross section to maintain an appreciable but nonscouring velocity during periods of maximum flow; on steep slopes drop structures may be required in the ditches. Banks of the waste-water ditch must be protected against erosion by surface-water inlet structures or by establishing vegetation on flattened slopes.

### Subsurface-Water Disposal

Excess ground water must be removed by deep open ditches or tile to provide an effective root-zone depth. The source of the excess ground water, whether seepage from ditches and reservoirs or a high water table, has a bearing on the kind of subsurface disposal and its layout. High water tables must be lowered to a depth that permits a normal root zone for the crop to be grown.

### Interceptor Drains

Interceptor drains generally consist of a single tile line or deep open drains installed along the base of a hill, parallel to a leaking canal, or around a leaking reservoir to intercept ground-water flow and prevent movement of water into a problem area. Tile drains are commonly used as interceptors because the drain must be located according to ground-water conditions, which generally do not correspond to field boundaries, fences, or property lines.

### Relief Drains

Relief drains are used to lower a high water table in areas of slight or stagnant ground-water flow that cannot be intercepted effectively. They are usually planned as a series of lateral tile lines in a gridiron or herringbone pattern in which each line is connected to a main that leads to an open drain. Relief drains are laid parallel to the direction of ground-water flow.

### Wells

A high water table in areas in which the soils are underlain by porous sand or gravel aquifers can be lowered by pumping. Often the pumped water can be used for irrigation if it is of satisfactory quality. Detailed subsurface and ground-water studies are needed to determine the possibility of sufficiently lowering the water table by this means.

In some areas in which artesian pressure maintains the water-table level at or near the ground surface, relief wells are used with subsurface drains. They are used if depth to the artesian aquifer is greater than practical drain depth and if the slowly permeable overlying material does not permit the ground water to move freely to the drain. Relief wells are connected to subsurface drains and extend through the slowly permeable soil layer into more permeable materials below. The water under pressure rises to the drain and is carried away. If the slowly permeable layer is only a few feet lower than the usual depth of the drains, relief wells can be put in open ditches by overdigging at intervals.

### Outlets

Satisfactory outlets for disposal conduits must either be available or be planned for. They must be large enough to carry the expected maximum amount of water from disposal conduits. Typical outlets are large open ditches or natural streams. If topography does not permit disposing of waste water by gravity flow, pumping units and other needed appurtenant structures must be provided. The water can be drained to open pits or sumps and then be pumped to a surface outlet for disposal. In some places water collected in the sump can be used for irrigating lower fields or it can be pumped back and reused.

## Water Measurement

Irrigation water must be measured if it is to be used efficiently. The principal objective of measuring irrigation water is to permit efficient distribution and application. By measuring water, a farmer knows how much water is applied during each irrigation.

Plan for enough measuring devices. Locate the main measuring device at the headgate or farm source of supply. If all the irrigation water is to be delivered to one field at a time, this main measuring device may be the only one needed for measuring the water supply to the various fields. But if the supply is divided between two or more ditches, measuring devices are needed at each ditch. Generally they can be built into other ditch structures, such as drops, checks, or turnouts. If the supply is delivered by pipelines, flow can be measured by various kinds of flow meters. It may be possible also to install an open-channel measuring device at the pipeline inlet structure or to install devices in overflow stand pipes or control boxes.

The various kinds of measuring devices are explained fully in chapter 9, Measurement of Irrigation Water, which gives information on constructing and installing various simple measuring devices and the necessary discharge tables and charts.

# Irrigation Guides

The irrigation guides used in the Soil Conservation Service give the basic design criteria for all conservation irrigation methods recommended for specific combinations of soils, slopes, crops, water supply, and climate. They include groupings of all the major irrigated soils, the adapted crops, and the appropriate design criteria. They also provide some guides for conservation irrigation water management.

## Area Covered

Irrigation guides generally are prepared on a problem or resource area basis. The primary factor determining the size of the area covered is similarity in design criteria based on soils, topography, and climate. Usually the smallest area included in a guide is a soil conservation district and the largest area is a State. All combinations of local conditions generally are covered in a guide so that an irrigation planner knows the irrigation practices recommended for any conditions in the area.

## Content

Irrigation guides do not include all the technical standards needed for or associated with a complete conservation program on irrigated land. They give necessary design information pertaining to the soil in a given field, the crop to be irrigated, and the requirements for water application. They do not include technical standards for land leveling, ditch construction, canal lining, irrigation structures, and other hydraulic design features. The information in the guides is given under three main headings--soils, crops, and irrigation specifications.

### Soils

Soils having similar physical characteristics for irrigation are grouped together. This grouping takes into account depth, texture, permeability, water-holding capacity, and intake characteristics. Symbols for soils are the same as those on the soil maps for the area. The effective soil depth is tabulated by successive layers or horizons beneath the surface. These depths are average depths for all the soils in a group. The available water holding capacity is shown for each depth or horizon.

### Crops

The crops usually considered to be adapted locally to each soil group are listed as well as the average soil depth from which the crops extract moisture. The guide lists the recommended amount of moisture to be replaced in a normal irrigation for each crop listed, the design consumptive-use rate of each crop, and the irrigation frequency during the period of maximum consumptive use. The irrigation frequency is the recommended maximum number of days that can be allowed between irrigations during periods of maximum water use without rainfall.

## Irrigation Specifications

This section of the guide provides the information necessary to determine the best irrigation method and the basic data for its design. The conservation irrigation methods suited to each soil group and the crops to be grown are listed as well as the intake-family design intake rate for furrows and corrugations and the design application rate for sprinklers. Stream sizes for the adapted surface methods are given for the design slope groups and the maximum length of run, estimated field efficiency, gross irrigation application, and estimated number of hours required to apply the water.

## Use

For good irrigation water management, a farm irrigation system must be designed to fit the crops and soils to be irrigated. The local irrigation guide provides the basic information needed to design such a system. After determining the kind of soil in the field to be irrigated and selecting the crop or crops, you must choose a method of applying irrigation water. The guide shows the method or methods of water application that can be used successfully for the crop and site conditions in the field to be irrigated and the basic design requirements.

The following example shows how to use an irrigation guide. Figure 3-77 is a guide for all irrigated sections of Kansas. The soil is Crete silty clay loam, the slope is 0.2 percent, and the crop to be irrigated is corn. Column 5 indicates that, for 0.0 to 0.25 percent slopes, corn grown on this soil has a moisture-extraction depth of 4 feet, requiring a net application of 4.3 inches of water for a normal irrigation (column 6). The peak-period consumptive-use rate or design rate for corn is 0.29 inches per day (column 7), and the irrigation frequency for the period of maximum consumptive use is 15 days (column 8). Column 9 shows that corn grown on this soil can be either furrow irrigated or sprinkler irrigated. Now assume that the farmer prefers the furrow method of water application and will plant his corn on a 40-inch spacing. Find the 40-inch spacing in column 12, and note to the left that the maximum allowable stream is 50 gallons per minute (column 11) and that the estimated average intake is 1.3 gallons per minute per 100 feet (column 10). Follow the 40-inch line to the right. Column 13 shows that the maximum length of run is 1,870 feet; the estimated efficiency is 70 percent (column 14), requiring 6.2 inches for the gross irrigation application (column 15). The estimated time required to make this application is 14 hours (column 16).

You must then fit the design information from the guide to the field to be irrigated. If the field is considerably longer than the maximum permissible length of run, you must use two shorter lengths of run to irrigate the field properly. Other soil conditions in the field may necessitate further revisions. If the extraction depth is less than 4 feet because of soil conditions, the amount of moisture to be replaced at each irrigation is also less, which in turn affects the gross application, the time estimated for applying the irrigation, and the length of run.

# IRRIGATION GUIDE

U. S. DEPT. OF AGRICULTURE
SOIL CONSERVATION SERVICE

| SOILS | | | CROPS | | | | | IRRIGATION SPECIFICATIONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOIL MAPPING SYMBOL | PROFILE DESCRIPTION | AVAILABLE MOISTURE HOLDING CAPACITY by feet of depth (inches) | LOCALLY ADAPTED CROPS | MOISTURE EXTRACTION DEPTH (feet) | NET MOISTURE TO BE REPLACED EACH IRRIGATION (inches) | PEAK PERIOD CONSUMPTIVE USE RATE (in./day) | IRRIGATION FREQUENCY DURING PERIOD OF MAXIMUM CONSUMPTIVE USE (days) | ADAPTED CONSERVATION IRRIGATION METHODS | INTAKE FAMILY Border or Flooding; Sprinkler in./hr.; Furrow or Corrugation g.p.m./100' | Stream Size Border or Flooding Unit Stream c.f.s.; Furrow or Corrugations Max. Stream g.p.m.; Sprinklers in./hr. | USUAL BORDER WIDTH feet; FURROW OR CORRUGATION SPACING inches | MAX. LENGTH OF RUN (feet) | EST. FIELD EFF. (%) | GROSS IRRIGATION APPLICATION (inches) | ESTIMATED TIME REQUIRED (hours) |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| | | | | | | | Slope Group 0.0% to 0.1% (Design Slope Level) | | | | | | | | |
| | Crete silty clay loam | 1 - 2.2 | Alfalfa | 6.0 | 6.2 | .28 | 22 | Level Bord. | 0.3 | .0023 | - | 1320 | 80 | 7.8 | 8.0 |
| | Richfield silt loam | 2 - 4.4 | | | | | | | | | | | | | |
| | Farnum loam | 3 - 6.4 | Corn | 4.0 | 4.3 | .29 | 15 | Level Bord. | 0.3 | .0040 | - | 1320 | 70 | 6.2 | 3.6 |
| | Elmo silty clay loam | 4 - 8.6 | | | | | | | | | | | | | |
| | Pond Creek silt loam | 5 -10.8 | Sorghum | 4.0 | 4.3 | .29 | 15 | Level Bord. | 0.3 | .0040 | - | 1320 | 70 | 6.2 | 3.6 |
| | Harney silt loam | 6 -12.3 | | | | | | | | | | | | | |
| | Bethany silt loam | | Sugar Beets | 4.0 | 4.3 | .29 | 15 | Level Bord. | 0.3 | .0040 | - | 1320 | 70 | 6.2 | 3.6 |
| | Lubbock silty clay loam | | | | | | | | | | | | | | |
| | | | Wheat | 4.0 | 4.3 | .25 | 17 | Level Bord. | 0.3 | .0040 | - | 1320 | 70 | 6.2 | 3.6 |
| | Deep, well drained | | Soy Beans | 3.0 | 3.2 | .30 | 11 | Level Bord. | 0.3 | .0057 | - | 1320 | 65 | 4.9 | 2.0 |
| | upland soils with loam | | | | | | | | | | | | | | |
| | to silty clay loam | | Grass-Tame | 3.0 | 3.2 | .26 | 12 | Level Bord. | 0.3 | .0057 | - | 1320 | 65 | 4.9 | 2.0 |
| | surface layers; clay | | | | | | | | | | | | | | |
| | loam to silty clay sub- | | | | | | Slope Group 0.0% to 0.25% (Design Slope 0.2%) | | | | | | | | |
| | soils and permeable | | | | | | | | | | | | | | |
| | substrata. | | Alf.& S.Cl. | 4.6 | 5.0 | .29 | 17 | Border | 0.3 | .0020 | 30--60 | 2640 | 70 | 7.2 | 8.4 |
| | (0% to 7% slopes) | | | 6.0 | 6.2 | .28 | 22 | Sprinkler | 0.2 B | - | - | - | 70 | 8.9 | - |
| | | | | | | | | | 0.3 C | - | - | - | 70 | 8.9 | - |
| | | | Corn | 4.0 | 4.3 | .29 | 15 | Furrow | 1.1 | 40 | 36 | 1660 | 70 | 6.2 | 15.0 |
| | | | | | | | | | 1.3 | 50 | 40 | 1870 | 70 | 6.2 | 14.0 |
| | | | | | | | | Sprinkler | 0.2 B | - | - | - | 70 | 6.2 | - |
| | Roxbury silty clay loam | | | | | | | | 0.3 C | - | - | - | 70 | 6.2 | - |
| | Dale silt loam, clay | | Sorghum | 4.0 | 4.3 | .29 | 15 | Border(Dr.) | 0.3 | .0025 | 30--60 | 2640 | 70 | 6.2 | 5.8 |
| | loam | | | | | | | Furrow | 0.8 | 20 | 20 | 1140 | 70 | 6.2 | 11.5 |
| | | | | | | | | | 1.0 | 30 | 30 | 1420 | 70 | 6.2 | 14.0 |
| | Detroit Silty clay loam | | | | | | | | 1.3 | 50 | 40 | 1870 | 70 | 6.2 | 14.0 |
| | | | | | | | | Sprinkler | 0.2 B | - | - | - | 70 | 6.2 | - |
| | | | | | | | | | 0.3 C | - | - | - | 70 | 6.2 | - |
| | Deep, well drained | | | | | | | | | | | | | | |
| | alluvial soils with | | Sugar Beets | 4.0 | 4.3 | .29 | 15 | Furrow | 0.8 | 20 | 22 | 1140 | 70 | 6.2 | 12.6 |
| | silt loam to silty clay | | | | | | | Sprinkler | 0.2 B | - | - | - | 70 | 6.2 | - |
| | loam surface layers; | | | | | | | | 0.3 C | - | - | - | 70 | 6.2 | - |
| | clay loam to silty clay | | | | | | | | | | | | | | |
| | loam subsoils and | | Wheat | 4.0 | 4.3 | .25 | 17 | Border | 0.3 | .0025 | 30--60 | 2640 | 70 | 6.2 | 5.8 |
| | permeable substrata. | | | | | | | Furrow | 1.0 | 30 | 30 | 1420 | 70 | 6.2 | 14.0 |
| | (0% to 2% slopes) | | | | | | | | 1.3 | 50 | 40 | 1870 | 70 | 6.2 | 14.0 |
| | | | | | | | | Sprinkler | 0.2 B | - | - | - | 70 | 6.2 | - |
| | | | | | | | | | 0.3 C | - | - | - | 70 | 6.2 | - |
| | | | Soy Beans | 3.0 | 3.2 | .30 | 11 | Border(Dr.) | 0.3 | .0035 | 30--60 | 2640 | 70 | 4.6 | 2.1 |
| | | | | | | | | Furrow | 1.0 | 20 | 20 | 980 | 70 | 4.6 | 6.8 |
| | | | | | | | | | 1.2 | 30 | 30 | 1240 | 70 | 4.6 | 8.5 |
| | | | | | | | | Sprinkler | 0.2 B | - | - | - | 70 | 4.6 | - |
| | | | | | | | | | 0.3 C | - | - | - | 70 | 4.6 | - |
| | | | Dry Beans | 3.0 | 3.6 | .28 | 11 | Furrow | 1.0 | 20 | 20 | 980 | 70 | 4.6 | 6.8 |
| | | | | | | | | | 1.2 | 30 | 30 | 1240 | 70 | 4.6 | 8.5 |
| | | | Grass | 3.0 | 3.2 | .26 | 12 | Border | 0.3 | .0035 | 30--60 | 2640 | 70 | 4.6 | 2.1 |
| | | | | | | | | Sprinkler | 0.2 B | - | - | - | 70 | 4.6 | - |
| | | | | | | | | | 0.3 C | - | - | - | 70 | 4.6 | - |
| | | | | | | | Slope Group 0.25% to 0.6% (Design Slope 0.4%) | | | | | | | | |
| | | | Alf.&S.Cl. | 3.7 | 4.0 | .29 | 14 | Border | 0.3 | .0025 | 30--60 | 2640 | 70 | 5.7 | 5.3 |
| | | | | 6.0 | 6.2 | .28 | 22 | Sprinkler | 0.2 B | - | - | - | 70 | 8.9 | - |
| | | | | | | | | | 0.3 C | - | - | - | 70 | 8.9 | - |
| | | | Corn | 4.0 | 4.3 | .29 | 15 | Furrow | 0.8 | 25 | 36 | 1290 | 70 | 6.2 | 20.5 |
| | | | | | | | | | 0.8 | 25 | 40 | 1290 | 70 | 6.2 | 23.0 |
| | | | | | | | | Sprinkler | 0.2 B | - | - | - | 70 | 6.2 | - |
| | | | | | | | | | 0.3 C | - | - | - | 70 | 6.2 | - |
| | | | Sorghums | 3.7 | 4.0 | .29 | 14 | Border(Dr.) | 0.3 | .0025 | 30--60 | 2640 | 70 | 5.7 | 5.3 |
| | | | | 4.0 | 4.3 | .29 | 16 | Furrow | 0.7 | 20 | 20 | 1140 | 70 | 6.2 | 13.0 |
| | | | | | | | | | 0.8 | 25 | 30 | 1290 | 70 | 6.2 | 17.0 |
| | | | | | | | | | 0.8 | 25 | 40 | 1290 | 70 | 6.2 | 23.0 |
| | | | | | | | | Sprinkler | 0.2 B | - | - | - | 70 | 6.2 | - |
| | | | | | | | | | 0.3 C | - | - | - | 70 | 6.2 | - |
| | | | Sugar Beets | 4.0 | 4.3 | .29 | 16 | Furrow | 0.7 | 20 | 22 | 1140 | 70 | 6.2 | 14.5 |
| | | | | | | | | Sprinkler | 0.2 B | - | - | - | 70 | 6.2 | - |
| | | | | | | | | | 0.3 C | - | - | - | 70 | 6.2 | - |
| | | | Wheat | 3.7 | 4.0 | .25 | 16 | Border | 0.3 | .0025 | 30--60 | 2640 | 70 | 5.7 | 5.3 |
| | | | | 4.0 | 4.3 | .25 | 17 | Furrow | 0.8 | 25 | 30 | 1290 | 70 | 6.2 | 17.0 |
| | | | | | | | | | 0.8 | 25 | 40 | 1290 | 70 | 6.2 | 23.0 |
| | | | | | | | | Sprinkler | 0.2 B | - | - | - | 70 | 6.2 | - |
| | | | | | | | | | 0.3 C | - | - | - | 70 | 6.2 | - |
| | | | Soy Beans | 3.0 | 3.2 | .30 | 11 | Border(Dr.) | 0.3 | .0028 | 30--60 | 2640 | 70 | 4.6 | 3.9 |
| | | | | | | | | Furrow | 0.9 | 20 | 20 | 980 | 70 | 4.6 | 7.5 |
| | | | | | | | | | 1.0 | 25 | 30 | 1110 | 70 | 4.6 | 10.0 |
| | | | | | | | | Sprinkler | 0.2 B | - | - | - | 70 | 4.6 | - |
| | | | | | | | | | 0.3 C | - | - | - | 70 | 4.6 | - |
| | | | Dry Beans | 3.0 | 3.2 | .28 | 11 | Furrow | 0.9 | 20 | 20 | 980 | 70 | 4.6 | 7.5 |
| | | | | | | | | | 1.0 | 25 | 30 | 1110 | 70 | 4.6 | 10.0 |

Figure 3-77.--Irrigation guide for all irrigated sections of Kansas.

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