Chapter 15 Irrigation

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Introduction

Irrigation is the application of water to the land to provide adequate moisture for crop production. This practice includes the development of the water supply, the conveyance system, the method of application, and the waste water disposal system, along with the necessary management to achieve the intended purpose.

Irrigation is necessary because rainfall often does not occur at the appropriate time or is inadequate for crop needs. Rainfall distribution is seldom ideal during the growing season. In the more arid parts of the United States, rainfall during the growing season is far short of most crop needs. Even in areas of high seasonal rainfall, crops often suffer from a lack of moisture for short periods during some part of the growing season.

A drought period can be defined as any number of consecutive days in which the available moisture in the soil has been so reduced by plant use and surface evaporation that plant growth and quality are adversely affected. The interval between a maximum supply of available moisture and the beginning of a drought period varies widely. This interval depends on the ability of the soil to store moisture, the rooting habits of the crop, the incidence of rainfall, and the evapotranspiration rate. See Chapters 1 and 3, Section 15, SCS National Engineering Handbook.

Advantages of Irrigation

Many benefits are obtained from the proper use of irrigation. Where lack of moisture would limit crop production, irrigation can be expected to increase crop yields. And, by careful control of the amount of moisture in the soil, higher quality crops that bring higher market prices can be produced each year. For example, irrigation can be used to counteract high or low temperatures; to eliminate short droughts that reduce quality; or, by being withheld, to allow a curing-out period prior to harvest.

For certain crops, particularly fruits and vegetables, the difference between profit and loss often depends on the time the crop reaches the market. Proper irrigation aids prompt germination and continuous plant growth, making it possible to regulate planting dates and time of maturity more closely.

Fertilizers do not increase plant growth unless moisture is available. With irrigation, fertilizers can be made available for plant use almost immediately and more of the fertilizer applied may be used effectively. Applying soluble fertilizers through irrigation water is a common practice. With sprinkle irrigation, this practice offers a saving in labor, requires a minimum of fertilizing equipment, and the depth of penetration can be closely controlled.

High-value cash crops, such as strawberries, cranberries, tomatoes, and citrus, can be provided some protection from frost and freeze damage through water applications just before and during periods of freezing temperatures.

Applying irrigation water immediately following transplanting greatly increases plant survival, thereby reducing costs of replacing plants. The water settles the soil into close contact with the root system. Sometimes an application is made just before transplanting if soil moisture is not up to field capacity.

Efficient irrigation promotes better use of the land in accordance with its capabilities and stabilizes yields of adapted crops. Irrigation also makes possible the seeding and prompt germination of soil improvement crops at the proper time during the growing season and helps to establish vegetative cover on eroded areas.

For additional guidance on application of fertilizers, soil amendments, and frost control, see SCS National Engineering Handbook, Section 15.

Irrigation does not necessarily ensure high crop yields and large profits. It should be used only on those soils that, if properly treated and managed, are capable of producing sustained high yields of irrigated crops. These soils are indicated in irrigation guides.

The water supply must be large enough to meet crop needs on the acreage to be irrigated and must be of suitable quality. The water must also be both economically accessible and legally available to the irrigator.

The irrigation system must be designed to divert water from the supply source, deliver it to the irrigated area, and apply it to the crop in an amount and rate that will meet consumptive use requirements of the crop without causing erosion or other damage to the land. The designed system should be practical, durable, and efficient.

The addition of irrigation to a farming operation usually increases labor and capital requirements. Very often labor is required for irrigation at a time when other crops must be planted, cultivated, or harvested. Additional capital is required both for the initial installation of the irrigation system and the operation and maintenance of the system, at least through the first irrigation season.

The best irrigation system can fail if not managed properly. In addition to the basic physical requirements, successful irrigation requires the use of good irrigation management practices. The irrigator should develop and follow a plan that specifies such practices as irrigation water management, use of adapted seed varieties of good quality in proper plant populations, fertility management, conservation cropping systems, and good cultural practices to control weeds, insects, and plant diseases.

Returns must be adequate to make irrigation profitable. The increase in crop value as a result of irrigation must exceed the cost of purchasing, installing, and operating the irrigation system.

Factors in Planning

The objective of irrigation planning is to ensure that the type of irrigation system installed will meet the needs of the operator, fit the requirements of the soil and proposed crops, and provide irrigation water management on the land (fig. 15-1). To achieve this objective, several factors must be considered during irrigation planning.

Soils

The soil is one of the most important factors to consider in irrigation planning. It must be capable of sustaining yields large enough to pay for the installation and operation of an irrigation system in addition to normal farming costs, and it must do this without significant deterioration over long periods of time.

A soil map is essential. It is the basis for determining whether the soils are irrigable, and is used by the planner to match the irrigation system with the soil. If the planner has only a standard dryland soil survey and determines that the information is not detailed enough to use in making necessary decisions, a supplemental irrigation soil survey should be used.

Adequate soils information enables irrigation planners to make decisions based on important soil properties such as intake rate, water-holding capacity, permeability, depth, slope, erosion hazard, water table location, drainage requirement, and salinity hazard. The use of these properties as specific planning and design criteria and to determine irrigation limitations is discussed in detail in individual state irrigation guides, individual Soil Interpretations Records (SCS-SOILS-5), and the National Soils Handbook, Part II, §603.03.

Topography

Topographic information is essential for planning an irrigation system. As a minimum, surveys should include enough detail to show the source and elevation of the water supply for the area to be irrigated; landscape features such as fences, buildings, roads, and shelterbelts that may affect the design of the system; present field boundaries and direction of irrigation; location and capacity of permanent irrigation ditches, pipelines, and structures; location and capacity of temporary field ditches or portable pipes and flumes; and the drainage pattern of the farm including the location and capacity of ditches for waste-water disposal and other drainage structures.

The scale and contour intervals of topographic maps needed will vary, depending on site conditions and the methods of irrigation under consideration. The scale may range from 1 cm equaling 10 m (1 in equaling 100 ft) to 1 cm equaling 50 m (1 in equaling 200 ft), depending on the irregularity of the ground surfaces and the concentration of obstructive landscape features. Likewise, the contour interval may range from 0.1 to 3.0 m (0.5 to 10 ft), depending on the slope. The objective should be to provide a map containing all the necessary data at a scale large enough to display the irrigation plan without crowding. A complete grid survey usually is needed if land leveling is required (see Chapter 1).

Grid or contour maps are not always required for planning irrigation improvements. For example, in the partial reorganization of an existing system, the planning of grade control structures in a properly located ditch may only require a profile and cross section of the ditch with the turnout locations and elevations to field laterals noted. Likewise, the installation of a sprinkle system does not require the same detail of topographic information that is required for a surface irrigation system.

Water Supply

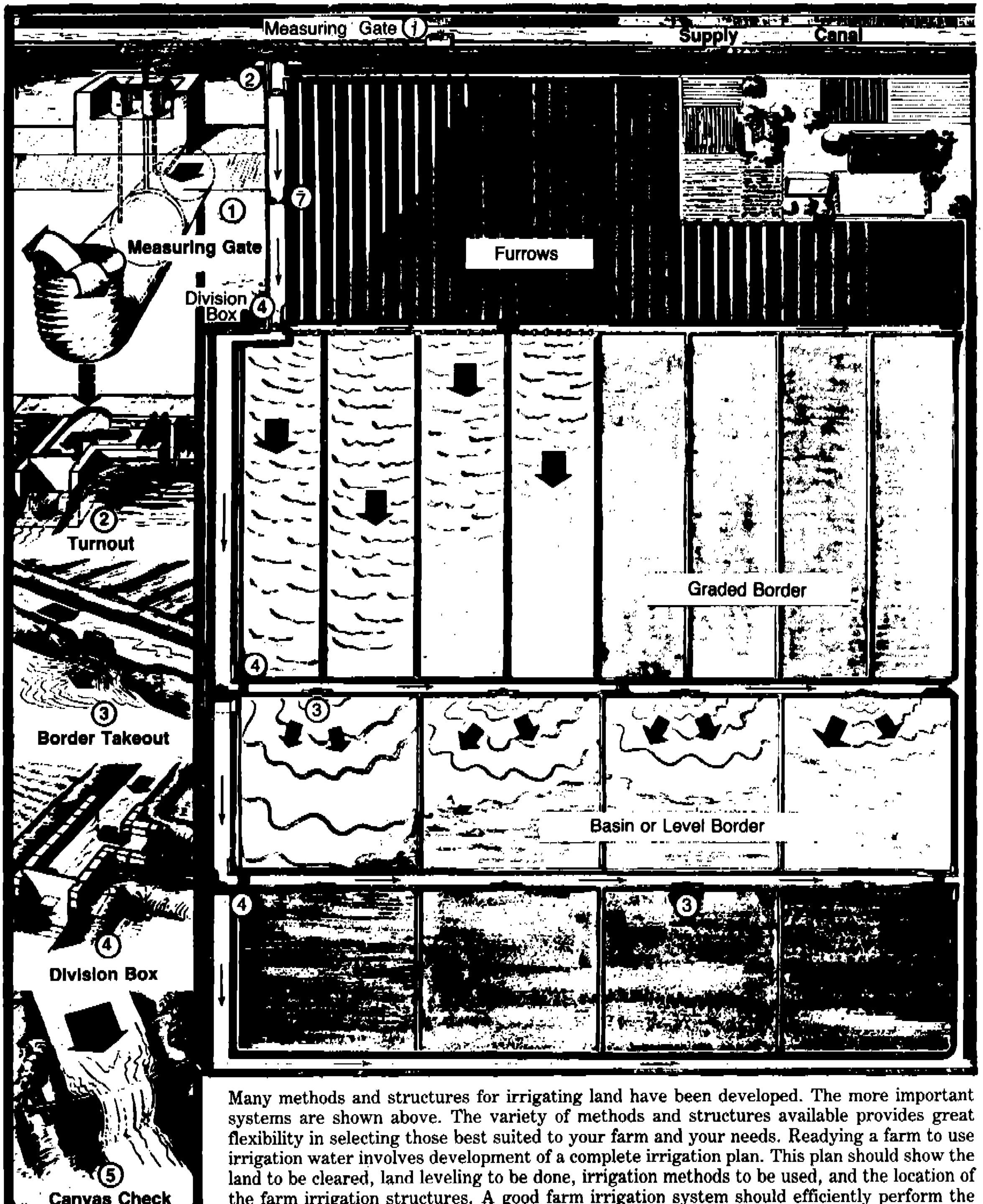
Compliance with state laws in obtaining water rights and in using irrigation water is the responsibility of the land user. However, SCS should advise the farmer about any water laws that may affect the plan or installation, and encourage the farmer to see a lawyer for interpretation of a law or for advice on a legal problem.

The quantity of water available for irrigation, the rate at which it can be delivered to the farm or fields, and the reliability of the supply must be determined (see table 11-2 in Chapter 11). The rate at which the water can be delivered to the farm usually is expressed in cubic meters per second, in miner's inches at the headgate or diversion, or in liters per second if from a pump.

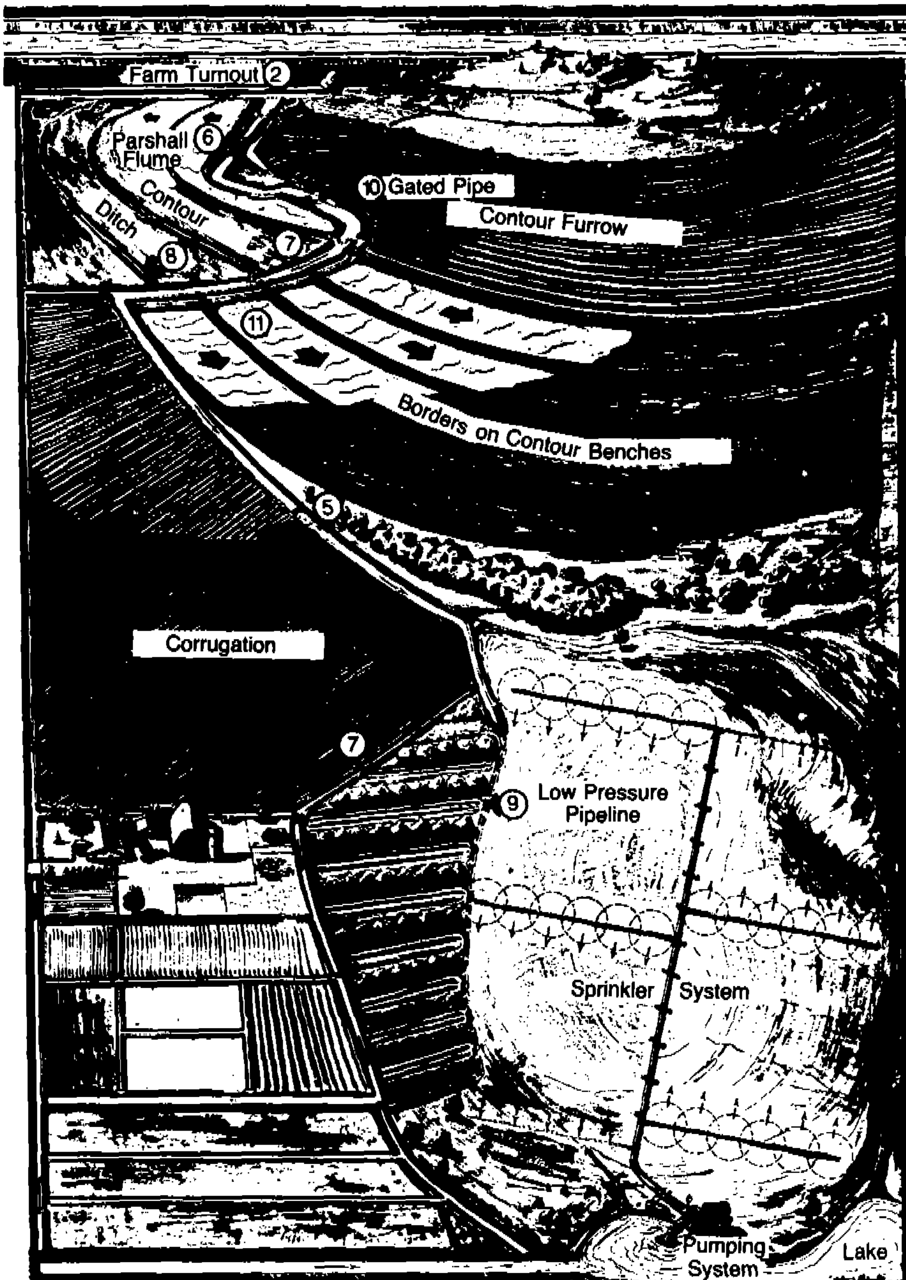
When irrigation water is transpired by plants, most of the salts that were in the water remain in the root zone unless there is enough rainfall or excess water provided in the next irrigation to leach

Figure 15-1

Some Elements Considered in Irrigation Planning



Many methods and structures for irrigating land have been developed. The more important systems are shown above. The variety of methods and structures available provides great flexibility in selecting those best suited to your farm and your needs. Readying a farm to use irrigation water involves development of a complete irrigation plan. This plan should show the land to be cleared, land leveling to be done, irrigation methods to be used, and the location of the farm irrigation structures. A good farm irrigation system should efficiently perform the following functions: (a) deliver water to all parts of the farm when needed, (b) deliver water in amounts needed to meet crop demands during peak use periods, (c) provide complete control



of water, (d) measure the amount of water at entry into farm irrigation system, (e) divide water in required amounts for use in different fields, (f) dispose of waste water, (g) provide for reuse of water on the farm, (h) allow free, easy movement of farm machinery, and (i) distribute water evenly into the soil of each field. In performing these functions, conservation of the water and land resources is a basic consideration. Irrigation and cropping methods that best fit the particular soil, slope, crop, and water supply should be used. This is conservation irrigation and it makes possible irrigation without soil erosion damage, saline or alkaline accumulation, water logging, or undue water loss.

the salts downward. In areas where the water quality is not known, tests should be made and evaluated by soil scientists or other specialists. The total concentration of soluble salts, the relative proportion of sodium to other cations, the presence of toxic amounts of boron or other elements, and the relative concentration of bicarbonates to calcium and magnesium should be determined. Facilities to test water quality are available through state agricultural colleges, public health departments, and commercial laboratories.

Erosion Control and Drainage

The irrigation planner is faced with simultaneously meeting the following three objectives: (1) apply water efficiently without causing erosion, (2) protect against erosion caused by rainfall, and (3) provide required surface and subsurface drainage.

The physical layout requirements for proper irrigation are often directly opposed to the physical requirements for protecting the land against erosion by rainfall. This is especially true with surface methods of irrigation. To protect a field against erosion caused by storms, it is often desirable to lay out the rows so the furrows are nearly level; however, for water application it may be easier to install a less efficient system by running the rows directly downslope. Using contour irrigation with or without terraces and contour bench leveling to modify slope often satisfy both requirements. In other instances, conventional erosion control practices are installed and the irrigation water is applied by sprinklers.

Similarly, the needs for drainage and irrigation are not necessarily compatible. On some soils it may be desirable to apply irrigation water by ponding, such as by the use of level borders, but such a practice may not be compatible with the drainage requirement for removal of excess storm water. On the other hand, land leveling for irrigation usually helps the surface drainage of a field by eliminating small ponded areas.

The application of irrigation water may change the balance between recharge and discharge of the ground water, which may result in changes in the elevation of the water table. Usually, when water is diverted from an outside source for application to an area, the water table rises and may reach a point where subsurface drainage is required. When irrigation water is pumped from the water table, the water table may drop. If subirrigation is the method used, subsurface drainage must necessarily be of a controlled type.

When the planner has met the requirements for efficient irrigation, effective erosion control, and adequate surface and subsurface drainage, he or she has developed a plan that sets the framework for conservation irrigation by the farmer.

Farm and Ranch Enterprises

An investigation for planning an irrigated farm is not complete until the type of enterprise that the farmer plans to develop is known. The crops to be grown, the labor available, and the intensity of the operation — all influence the layout. Although the irrigator may have an opinion regarding the best methods and layout, it is the job of the planner to suggest alternatives that will provide a sound basis for the final decision.

The irrigation plan describes major components of the irrigation system and their operation. It lists the basic soils, agronomic and engineering data as they apply to the specific irrigated unit, and spells out in detail how irrigation water management is to be achieved.

Economics

The economics of irrigation must be considered during irrigation planning. The planner needs to show that the benefits will be sufficient to justify the cost of purchasing, installing, and operating the irrigation system and that there will be a reasonable return on time, labor, and investment.

The actual cost of the system and its installation must be estimated. This cost will vary greatly depending on the type of system, size and length of distribution lines, water source, number and type of water control structures, and other significant field conditions. The cost of operation and maintenance needs to be included. This cost may be annual power costs, water assessments, repair, maintenance, insurance, or taxes. Any additional crop production costs should be estimated, and it may be wise to develop an annual sinking fund for future equipment replacement.

The returns or benefits to be accrued from irrigation should be estimated. They may consist of only the difference between the value of irrigated crops and dryland crops. Or they may include such intangible items as ensuring a stabilized farm income, ensuring a feed supply for a livestock operation, allowing an increase in the production of the farming operation without adding land, and increasing the value of the land.

Basic Design Criteria

Design criteria for each irrigation method are contained in state irrigation guides and the appropriate chapters in Section 15 of the SCS National Engineering Handbook. Design criteria for irrigation practices are found in the section "Practice Standards and Specifications" in the SCS National Handbook of Conservation Practices, and in the local field office technical guide.

Level Borders

The level border method of irrigation consists of surrounding a nearly level area with a low dike and quickly filling the area with the desired amount of water. A temporary pond is created until the soil absorbs the water. Both row crops and close-grown crops are adapted to use with level borders as long as the crop is not affected by temporary inundation or is planted on beds so that it will remain above the water level. Level borders are useful if leaching is required to remove salts from the soil.

As the intake rate of the soil increases, the stream size must be increased or the length of the runs shortened so that water will cover the area within the required time. Large irrigation streams usually require higher border ridges; however, they can be used if the conditions specified in the guide are met.

The area within a level border must be carefully leveled. Preferably, there should be no cross slope, and the total fall within the length of the border should not exceed half the normal net water application depth.

Graded Borders

With the graded border method of irrigation, the field is divided into parallel rectangular strips separated by small earth dikes called border ridges. These ridges are broad and low enough so that they can be planted and harvested with the rest of the field.

The graded border method is adapted to close-grown crops. A stream of water is introduced into the upper end and it flows across the field in a sheet between the border dikes. Efficiency of irrigation application depends on selecting the proper stream size.

Border strips should not have more than 0.03 m (0.10 ft) of cross slope. Thus, on a field that has been leveled to a cross slope of 0.3 percent, the borders should not be more than 10 m (33 ft) wide; but with a cross slope of 0.2 percent, borders that are 15 m (50 ft) wide may be used. On steeper slopes (0.7 percent and greater) it may be necessary to use corrugations with the borders to spread the border stream adequately.

Ideally, graded borders should have a uniform slope downfield. If this is not possible, the steepest slope should not be greater than twice the flattest slope. Slope should either steadily increase or decrease in a downstream direction. Undulating slopes are inefficient.

Furrows

The furrow method of irrigation is used for row crops. Furrows are developed between the rows during planting and cultivating.

Graded Furrows

For the most efficient use of the graded furrow method, the largest stream practical without creating an erosion hazard should be used to force the water across the field, and then the stream should be cut back to a size that will keep runoff losses to a minimum for the remainder of the irrigation. A tail-water recovery system may be needed to increase irrigation efficiency. With level furrows, the initial stream should be used until the required amount of water is applied. The water should be ponded in the furrows until it is absorbed by the soil. The maximum stream size that may be used depends on the size, shape, and slope of the graded furrows and the erodibility of the soil.

In general, furrows run downslope; however, on smooth, uniform slopes, crops can be planted across the slope to reduce the gradient. Also, on this type of slope it is sometimes desirable to have the rows parallel to a fence or other boundary running across the slope. This is satisfactory as long as the furrows are deep enough and the soil is stable enough so that irrigation water or storm runoff does not break over from one furrow to another.

Contour Furrows

Contour furrows may be used on moderately steep slopes when medium deep furrows can be developed. They may be installed along with terraces on land that requires terraces for protection against erosion.

Contour furrows must be planted carefully. When the guidelines or terraces spread apart in the direction of flow, the lower guideline should be followed; when they come closer together, the rows are made parallel to the upper guideline. This ensures that every furrow has a grade at least equal to the grade of the guideline or terrace.

Corrugations

Corrugations are identical to furrows except that they are used with close-grown crops and may be spaced in accordance with the properties of the soil instead of the requirements of the crop.

Corrugations may be used with other methods to facilitate the spreading of water or to reduce crusting. They also are used between borders to irrigate a crop or to guide water to small ridges between contour ditches. When corrugations are used in this manner, the system design is based not on the specifications for corrugations but on the specifications for the methods they facilitate.

Contour Ditch

The contour ditch method is widely used for irrigating close-grown crops on steep slopes. Using this method, ditches are laid out across the slope on a slight grade. Water is released from the ditches by means of siphon tubes or openings in the ditchbank. Plowing a furrow on the lower side of the graded contour ditch so that the soil is thrown against the lower bank is a simple improvement that allows more uniform distribution of flow and generally increases the efficiency of this method.

Sprinkle

In sprinkle irrigation, water is sprayed into the air by means of perforated pipes or nozzles operated under pressure. Sprinkle systems can be classified as portable, solid-set, or self-propelled. There are many different types of systems within each of these broad classifications. Each type has certain advantages, disadvantages, or application characteristics that affect its suitability for a particular site. Most sprinkle systems are designed by manufacturer representatives or equipment dealers. It is very important, therefore, that the buyer is aware of the capabilities and limitations of the systems under consideration. For the designer to develop an adequate system design that fits the water supply and site conditions, he or she must have such basic information as the water-holding capacity and intake characteristics of the soil, consumptive use requirements of the crops to be grown, soil erosion susceptibility, and needed conservation measures.

Other information that will be useful to the buyer and designer of a sprinkle system is found in Chapters 3 and 11, Section 15, SCS National Engineering Handbook, and in the irrigation guide and the field office technical guide.

Subirrigation

The subirrigation method requires special site conditions that permit control of the water table through regulation of water application and drainage. This method is most often used on land that has a high water table and where subsurface drainage is needed to remove ground water and provide soil aeration. If a high water table is not inherent, a layer of slowly permeable material, or some other barrier, must exist at a depth that will permit the buildup of an artificial water table without excessive losses. Topography should be relatively flat and uniform. Soils must be deep enough to allow for any needed surface modification and to permit installation of the planned measures. Soil permeability must allow good vertical and horizontal movement of water.

A subirrigation system should apply water when irrigation is needed and remove water when drainage is required. Thus, an adequate irrigation water supply and an adequate drainage outlet must be available. The water conveyance and removal facilities may consist of (1) open ditches with water elevation control structures, (2) combination open channels and subsurface drains and control structures, or (3) buried pipelines, subsurface drains, and water control structures.

Each site is unique and requires special investigations. System designs must be developed to meet the site conditions. Therefore, these operations should be carried out by personnel who have considerable experience with this irrigation method.

Trickle

Trickle irrigation is the slow application of water on or beneath the surface layer, usually as drops, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line. Trickle irrigation includes a number of methods or concepts, such as drip, bubbler, and spray irrigation.

Drip irrigation applies water to the surface layer or below in discrete or continuous drops or in tiny streams through small openings. Often, the terms drip and trickle irrigation are considered synonymous. Discharge rates for widely spaced individual applicators are generally less than 20 L/hr (5 gal/hr) and for closely spaced outlets along a tube (or porous tubing) are generally less than 4 L/hr (1 gal/hr) per foot of lateral or tube.

Bubbler irrigation applies water to the surface layer as a small stream or fountain from an opening having a point discharge rate greater than that for drip irrigation but generally less than 4 L/min (1 gal/min). The applicator discharge rate normally exceeds the infiltration rate of the soil, and a small basin is usually required to contain or control the distribution of water.

Spray irrigation applies water to the surface layer by a small spray or mist. Air is instrumental in the distribution of water, whereas the soil is responsible in drip and bubbler irrigation. Discharge rates are generally less than 115 L/hr (30 gal/hr).

In trickle irrigation, water is dissipated from a pipe distribution network under low pressure in a predetermined pattern. The outlet device that emits water into the soil is called an "emitter." In spray irrigation, the outlet devices may be referred to as aerosol emitters, foggers, spitters, misters, or miniature sprinklers.

For wide-spaced permanent crops such as trees and vines, emitters are individually manufactured units that are attached by a barb or other means to a flexible supply line called the "emitter lateral," "lateral hose," or "lateral." For less permanent row crops such as tomatoes, sugarcane, and strawberries, the lateral with emitter outlets is manufactured as a disposable unit having either perforations spaced every 23 to 92 cm (9 to 36 in), as in double-chamber tubing, or having porous walls from which water oozes. For all types of trickle systems, the laterals are connected to supply lines called the "manifolds." Figures 15-2 and 15-3 show the basic components and layout of a typical trickle irrigation system.

With the trickle method, water can be metered to widely spaced trees and vines or to row crops planted on beds. Thus, this method is especially adapted to orchard, vineyard, and vegetable crops.

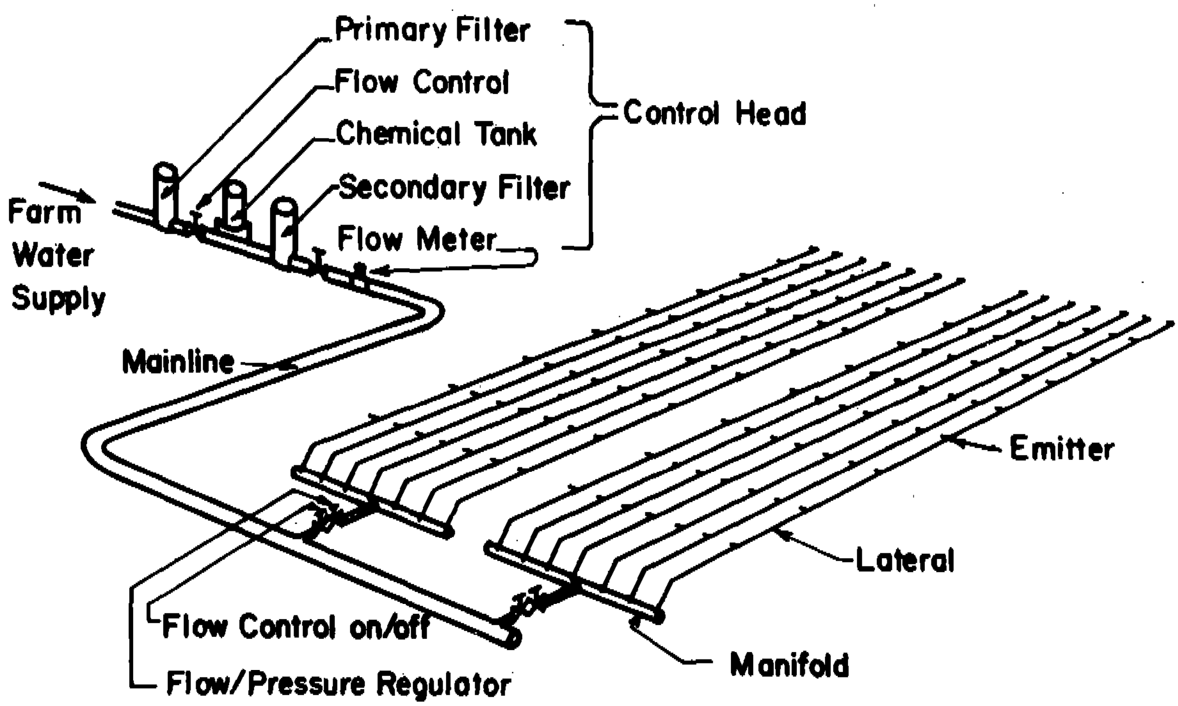


Figure 15-2 — Basic components of a trickle irrigation system.

Labor costs and water use can be reduced with trickle irrigation because these systems need to be regulated rather than tended, and much of the surface layer is never wetted by irrigation water. Efficient control and placement of fertilizer can be accomplished with trickle systems. These systems can be designed to operate efficiently on almost any topography.

The main disadvantages inherent in trickle irrigation systems are their comparatively high cost; susceptibility to clogging; their tendency to build up local salinity; and, where improperly designed, their extremely partial and spotty distribution of soil moisture.

Trickle irrigation systems are normally designed and managed to apply light, frequent applications of water and to wet only part of the soil. Therefore, the procedures used to compute water requirements, irrigation depth and frequency, and salinity controls for other methods of irrigation must be adjusted for trickle irrigation. For detailed information and design and evaluation procedures applicable to trickle irrigation, refer to Chapter 7, Section 15, SCS National Engineering Handbook.

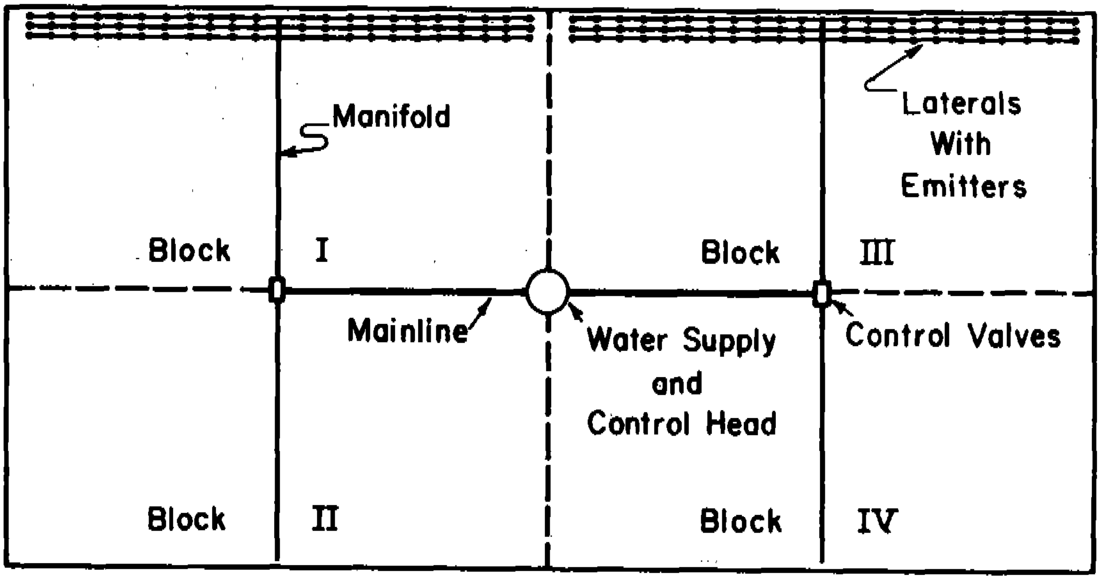


Figure 15-3—Typical two-station, split-flow layout for a trickle irrigation system with blocks I and III, or II and IV operating simultaneously.

Capacity

Irrigation water must be conveyed from its source through a system of canals, pipelines, or structures to the individual furrow border or sprinkler head. For projects or group systems, a canal system usually delivers the required flow to the farm headgate. The plan must provide conveyance from the headgate or farm source to the individual field and furrow. The conveyance system must have the capacity to deliver to the field a flow that is adequate to meet the largest size of stream required for the irrigation methods planned for the field and to meet the consumptive use of the crops to be grown, making provisions for the expected field irrigation efficiency.

Some waste results when transporting the water from the headgate or pump to the field. If the water is carried in buried or surface pipelines, this loss may be negligible. In lined ditches the loss will also be very slight, depending upon the type of lining and its condition. Water conveyed in open, unlined ditches may have considerable loss, sometimes 15 to 40 percent per kilometer (25 to 66⅔ percent per mile) or more on permeable soils. When unlined ditches are used, the farm requirement is equal to the field requirement plus the amount of the ditch losses.

Open Ditches

Some capacities and dimensions of permanent open ditches are given in exhibit 15-1. A ditch that will safely convey the required stream should be selected.

In designing a permanent ditch, a profile of the centerline, showing the location and elevation of the water supply and any required turnouts, crossings, drainage bypasses, and the like, is required. The water level at field turnout points must be high enough to provide the required flow onto the field surface. The water level required varies with the type of takeout structures, but the head should be at least 10 cm (4 in). Refer to Chapter 3, Section 15, SCS National Engineering Handbook for information on lined and unlined ditches.

Structures

In the selection of a specific structure, the depth of flow "d" should always equal the depth of flow in the ditch, and the structure capacity should equal or exceed the design flow capacity of the ditch. Standard structures should be used wherever possible. If a special design is required, the job should be designed in cooperation with someone having authority to approve it.

Criteria for certain types of irrigation structures are given in Chapter 6 of this manual. These criteria may be used to determine if a structure is adequate, even though it has not been built according to an SCS standard plan. In most instances it is desirable to exceed minimum requirements to provide longer life, better operation, or easier construction. Whenever possible, the farmers and contractors should be encouraged to utilize the standard plans already available.

Drops

Drops are placed in a ditch or canal to hold the velocity of the flow within allowable limits, to increase the head on turnout devices, or both. Velocity limitations for irrigation ditch and canal standards are described in the technical guide.

Drop structures should be placed so that, if needed, they can be used to divert water onto the land. A good rule to use for the location is to place the structure about 3.0 or 4.6 m (10 or 15 ft) downstream from the point where the water level is 0.15 m (0.50 ft) above the graded land surface. This procedure appears to place the structures on fill; however, since the line represents the water level and not the ditch bottom, the structure will always be on firm ground.

The height of drop structures used to lower water from one control point to another should be based on the economics involved and the desires of the farmer. Since two smaller drops take more materials and labor than one larger structure, the tendency in newly irrigated areas is to use fewer, higher drops and keep the cost down. In many of the older irrigated areas, the tendency is to use more small drops to eliminate deep ditches between structures. For small farm ditches the height of the drop in meters should not exceed 0.3 times the land slope in percentage. A drop more than 1 m (3 ft) high should seldom be used. With large streams this height is sometimes increased. On steep slopes it is often advisable to use a concrete-lined ditch section or pipeline to lower the water.

Turnouts should be placed so that it is not necessary to check the water above the design flow of the ditch, thereby providing a safety factor if water is turned down the ditch with the check flashboards still in place.

Crossings should be provided so that equipment will have access to all parts of the field. With pipe drop structures, a crossing can be provided by extending the length of the barrel and increasing the width of the fill.

Pipelines

Irrigation pipelines can be used for the same purposes as open channels or in place of open channels. Because the pipelines almost eliminate losses from evaporation and seepage, water distribution efficiency is high. They are particularly adapted to areas where seepage losses from ditches are high. Pipelines have an advantage over open ditches, where it is difficult to excavate and where it is necessary to carry water down steep slopes. Buried pipelines do not require as much land as ditches; therefore, the land can be used for other purposes. Pipelines require careful planning for correct location, capacity requirements, proper selection of materials, and construction methods. Generally, the services of an engineer are required. Chapter 3, Section 15, SCS National Engineering Handbook, gives further information on pipelines.

Measuring Devices

Measuring devices are needed so that the farmer knows how much water he or she is using and can make the necessary adjustments for efficiency. The simplest of all measuring devices is a weir, but it requires a loss of head to function accurately. When such a head loss cannot be tolerated, a Parshall flume or trapezoidal flume may be used. Many large ditch companies have measuring devices built into the headgates. Some pumping installations are equipped with flowmeters on the discharge line. Appropriate measuring devices should be considered as essential items for good irrigation water management. See Section 15, Chapter 9, of the SCS National Engineering Handbook for further information.

Land Leveling

For more efficient application of irrigation water by surface methods, it is often necessary to modify the topography. Such modification, made according to a plan providing for specific elevations at each point, is called land leveling.

The relief classes for surface-irrigated land are shown in exhibit 15-2. If the surface relief meets the standards for class D or E, only poor or very poor irrigation water efficiencies are possible, and leveling is required for conservation irrigation. The ideal land surface for surface irrigation has little or no cross slope and has a uniform downfield slope that is slight enough that erosion from rainfall and irrigation water is not a problem and adequate enough to provide good surface drainage. If the conditions are appropriate, the ideal land surface is flat in both directions. The slope limitations vary from location to location because of differences in soil and rainfall.

Some fields are ideal, requiring no leveling. Generally, however, it is necessary to do some leveling on each field. Standards for satisfactory leveling have risen over the years and farmers are deciding that it is worthwhile to relevel some fields. Many irrigation areas that are being leveled to a "C" class relief probably will eventually be leveled to "B" or even "A" class relief. For this reason, the planner should design the best job the farmer can afford. Details for designing, staking, and leveling land are given in the SCS National Engineering Handbook, Section 15, Chapter 12.

Water Disposal System

A complete water disposal system should be planned for each irrigated farm. This disposal system should be able to convey storm and irrigation runoff to an outlet without causing excessive erosion. It should be incorporated as part of the drainage design on lands that require or have a subsurface drainage system. On lands that require only surface water disposal, the drainage system should be built at the same time the lands are leveled, if possible.

In many cases the disposal system will use waterways designed principally to carry storm runoff. If irrigation tail water is to enter these waterways, special plantings and maintenance often must be specified.

Equipment

In addition to sprinkle systems, the farmer has a wide choice of portable irrigation equipment. This portable equipment has been developed to permit more accurate distribution of water and to reduce labor requirements.

Check Dams

Several types of canvas, plastic, and metal check dams are available for both lined and unlined ditches. These check dams are designed to block the flow in a ditch just below the point where the water is to be turned out. They can be placed at any location and are not in the way when a ditch needs to be cleaned or rebuilt. Most check dams are adjustable so that the water can be held at some constant level.

Siphon Tubes

Siphon tubes are widely used to withdraw water from an irrigation ditch. They range from 1 cm (0.4 in) in diameter to large fabricated siphons that carry as much as 57 L/s (15 gal/s). The small tubes usually are used for furrow irrigation, although a number of them may be used together for border or contour ditch irrigation.

For furrow irrigation, the tube sizes usually are selected so that two or three tubes per furrow will deliver the maximum stream recommended for the slope being irrigated. After the water has crossed the field, one tube is removed to provide the "cutback" stream. The approximate discharge of small aluminum siphon tubes is given in exhibit 15-3. The head shown is the difference in height in the supply ditch and the centerline of the discharge end of the tube or the water level in the furrow when the discharge end is submerged.

Gated Pipe

Gated pipe is made of lightweight metal or plastic and has small gates or openings spaced to match the furrows. The pipe comes in sections that are easy for one person to handle and is fitted with simple watertight connections. A slightly different product made of vinyl-coated glass, cloth, butyl, plastic, or canvas hose and equipped with small outlets can be used for the same purpose. Gated pipe reduces water losses during conveyance and provides a positive control of the water to each individual furrow. Operating heads of more than 0.6 m (2.0 ft) usually require "socks" on the opening to avoid erosion.

Computing the head loss in a reach of gated pipe with the gates closed is similar to computing it for any similar pipe. For the reach in which the gates are open, the friction is first computed as if the entire flow were carried the full length. The computed value is then multiplied by a factor which depends on the number of outlets. This factor is given in exhibit 15-4.

Some head is required at the last gate to produce flow through the gate. The head required depends on the type of gate used and the desired flow. Usually the head is less than 0.3 m (1.0 ft).

An example of a calculation on gated pipe follows. Assume that the flow of water needed is 63 L/s (17 gal/s) through a 20-cm (8-in) gated pipe 396 m (1,300 ft) long, and that 0.31 L/s (0.10 gal/s) must flow through each of the last 200 gates. Gates are spaced 1 m (3 ft) apart.

What is the total head loss if a 20-cm (8-in) pipe has a friction loss of 2.47 m per 100 m (2.47 ft per 100 ft) for a flow of 63 L/s (17 gal/s)?

Given:

Number of gates	200
Multiple gate factor (exhibit 15-4)	0.33
Length of pipe with gates open	204 m (670 ft)
Length of pipe with gates closed	192 m (630 ft)

Solution:

Open line loss (2.04 m) x 2.47 x 0.33	=	1.66 m
[(6.70 ft) x 2.47 x 0.33	=	5.40 ft]
Closed line loss (1.92 m) x 2.47	=	4.74 m
[(6.30 ft) x 2.47	=	15.60 ft]
Total loss	=	6.40 m (21.00 ft)

Methods of Measuring or Estimating Soil Moisture

To determine the required depth of irrigation water to be applied at any given time, the irrigator should first estimate or measure the amount of available moisture in the soil within the root zone depth. There are several methods of doing this. Additional information on the advantages and limitations of these methods are given in the SCS National Engineering Handbook, Section 15, Chapter 1.

Soil sampling and drying. This method involves sampling each type of soil in the field at desired depths and at several locations. The soil samples are weighed, dried, and weighed again. The difference in weight is equal to the weight of the moisture. Usually this is expressed as a percentage of the weight of the dry soil.

Tensiometer. The tensiometer consists essentially of a porous cup filled with water and connected by a continuous water column to a vacuum measuring device, either a gage or manometer. The cup is buried in the soil at the desired depth and measurements are read above ground on the vacuum indicator. This instrument measures soil moisture tension directly. A moisture characteristic curve for the particular soil being irrigated is required to convert moisture tension measurements into percentage of available moisture in the soil.

Electrical instruments. Electrical instruments operate on the principle that a change in moisture content produces changes in some electrical property of the soil or of an instrument inserted in the soil. In most cases this property is electrical conductivity. Electrodes are permanently mounted in conductivity units. These units are usually blocks made of nylon, fiberglass, or gypsum. These blocks are buried at the desired depth, and changes in the moisture content of the soil are reflected by changes in the electrical resistance in the blocks. Resistance or conductance meters are used to measure the resistance. It is necessary to calibrate the blocks in the field by comparing the resistance readings with the soil moisture contents determined by ovendrying samples taken from the same relative position as the blocks.

Gas pressure instruments. Instruments such as the carbide moisture tester utilize the principle of chemical drying of the soil sample. A reagent such as calcium carbide is mixed with the moist soil sample within a sealed chamber. The chemical reaction of the reagent and the soil moisture produces acetylene gas. The gas pressure registers on a gage that is calibrated to indicate the wet weight moisture percentage of the soil. Convenient tables are available to convert these values to dry weight moisture percentages. The reaction and readings normally require about 3 min per sample.

Feel and appearance method. This method is rather widely used to estimate the amount of available moisture in the soil. Samples are taken from various depths and at several locations in the field. A soil sampling tube, auger, or post-hole digger is used. The feel and appearance of the samples are compared with a table, or a guide such as exhibit 15-5, and the soil moisture level is thus estimated. With practice and experience the irrigator should be able to estimate the moisture level within 10 to 15 percent.

Evaporation pan method. This method uses the relationship of crop consumptive use to the evaporation from standard evaporation pans. Evaporation pan data are approximations of consumptive use and are not measurements of soil moisture. The amount of soil moisture used in a given period must be calculated. This calculation is made by applying a factor to the crop that is to be irrigated to the depth at which water evaporated from the pan during that period. This calculated amount then represents the soil moisture used by the crop.

Moisture accounting method. Consumptive use values are used to maintain a daily inventory of the remaining soil moisture. Starting at a time when the moisture level in the soil is known, a "bookkeeping" system is set up whereby the computed consumptive use is subtracted daily from the recorded available moisture in the soil. Rainfall and irrigation amounts are added to the moisture balance when received. The success of this method depends on accurate measurements of the water-holding capacity of the soil, determination of daily consumptive use rates, and measurement of rainfall and irrigation amounts.

Introduction

Irrigation water management practices are the timing and regulating of irrigation water applications so that the water requirements of the crop are satisfied without wasting water or losing soil. Water is applied in amounts that can be held in the soil for crop needs and at rates that do not cause runoff and erosion.

The irrigator provides the management, not the structure. For example, an irrigator may install a headgate to control the flow of water onto a field. The headgate itself provides no water management. The water is managed when the irrigator opens the gate to deliver water to the field or closes the gate to stop delivery. Before irrigating, the irrigator must decide, for example, when to open the gate, how far it should be opened, and when it should be closed. The ability to make sound water management decisions is the most important aspect of conservation irrigation water management.

To make sound decisions, the irrigator must understand the basic principles involved. He or she must have a general idea of how water is held in the soil for plant use and how much water the soil holds. The irrigator needs to know how to judge when irrigation is needed and how much is needed. He or she should have a general understanding of soil intake characteristics and of the required adjustments in stream sizes and time of water application according to the intake rates of the soils.

Regarding irrigation water management, the main objectives of SCS are to give farmers an understanding of conservation irrigation principles, show them how to judge the effectiveness of their own irrigation practices, and help them make needed adjustments in old systems or install new systems. The rest of this chapter provides guidance in meeting these objectives.

Basic Soil-Moisture-Plant Relationships

Available Water Capacity

An irrigator must understand the usable water capacity of soils. Lack of this knowledge generally results in overirrigation and wasted water.

When a soil is irrigated, water moves down through the voids or openings between soil particles, forming a film around each individual soil grain. This film is held tightly around the soil grains when small amounts of water are available. When the amount of water increases, the film becomes thicker and the surface tension decreases. When the film becomes so thick that the surface tension will no longer resist the pull of gravity, the extra water moves through the soil. The amount of water held around the soil grains against the pull of gravity is called the "field capacity" of the soil. This is the moisture condition of a well-drained soil a day or two after a thorough irrigation or rain.

As plants use water from the soil, the film around the soil grains becomes thinner and more tightly held. When the film becomes so thin that plants can no longer pull the water from around the soil grains, the soil is said to be at the "wilting point." Available water capacity of a soil is the amount of water that can be held between the limits of field capacity and wilting point.

While it may not be important that irrigators know how water is held in the soil for plant use, it is important that they know how much can be held and that there is a limit to the available moisture-holding capacity of each soil.

For irrigation, it is convenient to think of the available water capacity of soils as the depth of water in millimeters per millimeter (inches per inch) of soil depth. The moisture held in any given soil profile or crop root zone is the summation of the amounts held in each 0.3-m (1-ft) increment of the total depth.

Many determinations of the available water capacity of soils have been made. The available water capacity of some soils is shown in irrigation guides that have been prepared for specific irrigation areas. For those soils not covered in the irrigation guides the available water capacity can be estimated by using table 15-1.

Table 15-1.—General range of available moisture-holding capacities and average design values for normal soil conditions

Soil texture	Available water per millimeter of soil[1]	
	Range	Average
	mm	*mm*
Very coarse-textured sands and fine sands	0.04-0.08	0.06
Coarse-textured loamy sands and loamy fine sands	0.06-0.10	0.08
Moderately coarse-textured sandy loams and fine sandy loams	0.10-0.15	0.13
Medium-textured very fine sandy loams, loam, and silt loams	0.13-0.19	0.16
Moderately fine-textured sandy clay loams, clay loams, and silty clay loams	0.15-0.21	0.18
Fine-textured sandy clays, silty clays, and clay	0.13-0.21	0.17

[1]The figures are identical if converted to inches per inch of soil.

Crop Root Zone Depths

The total amount of water held available for plant use in any soil depends on the depth of the root zone. This root zone depth may be limited by the soil's characteristics, or the plant's root development characteristics. For example, a uniform, medium-textured soil is underlain by an impervious hardpan at a depth of 1.0 m (3.3 ft). The water that could be retained in this soil for use by deep-rooted crops, such as alfalfa, tomatoes, or orchards, would be limited by the depth to hardpan rather than by the normal root characteristics of the crop. However, the moisture that could be retained for shallow-rooted crops, such as ladino clover, onions, or lettuce, would be limited by the crop root zones, which are less than 1.0 m (3.3 ft). These crops must obtain their moisture from the upper part of the soil. The normal root zone depth of mature irrigated crops for each soil group is shown in the local irrigation guide.

Plant Moisture Requirements

Plants must have a continuous supply of readily available moisture to maintain rapid, vigorous growth. However, it is not necessary, feasible, or even desirable to maintain soil moisture in the root zone at field capacity. The objective for irrigation is to provide adequate moisture for crop production. This can be accomplished by providing a supply of moisture within the root zone of the crop held at sufficiently low tension to be easily available for crop use. Experience indicates that moisture tension conditions usually are satisfactory for good crop growth if water is applied about the time one-third to one-half of the available water in the root zone has been used.

Plants wilt and die when the moisture in the entire root zone approaches the wilting point. Growth may be slowed well before this moisture content is reached. Plants, however, do not use water at a uniform rate from all parts of the root zone. Water is used more slowly from the lower part of the root zone than from the upper part. Under normal irrigation conditions, plants obtain about 40 percent of their water from the upper quarter of the root zone, 30 percent from the second quarter, 20 percent from the third quarter, and about 10 percent from the bottom quarter. Thus, the upper part of the root zone may be approaching the wilting point while moisture is available at lower depths. To determine the true moisture condition, the entire root zone must be examined.

Consumptive Use Rates

The moisture used by plants plus the moisture that evaporates directly from the surface of the field is called consumptive use. The amount of moisture consumptively used in an irrigated field on any given day is related to the air temperature, the number of daylight hours, the crop, and the stage of crop growth. Other factors such as wind and relative humidity also affect consumptive use rates. All crops have relatively low consumptive use rates when they are young. Their highest rates rates usually occur as they approach the stage of maximum vegetative development. For comparable stages of crop growth, consumptive use rates are greater on long, hot summer days than on short, cool spring or fall days. As consumptive use rates indicate the rate of depletion of soil moisture, this information is helpful in estimating when irrigation will be needed.

Local irrigation guides show the estimated annual, monthly, and peak period consumptive use rates for the major crops grown in the area covered by the guides. Additional information on consumptive use determination is contained in Technical Release #21.

Evaluation Procedure

The effectiveness of a farmer's irrigation water management practices can be determined from a few simple field observations. No matter which irrigation method is used, certain principles apply.

1. Water should be applied when needed to maintain favorable soil moisture conditions for good crop growth.

2. The amount of water applied should be sufficient to reach field capacity in the root zone but should not greatly exceed this requirement. An exception to this may be in humid areas when a soil moisture deficit is planned to accommodate anticipated rainfall.

3. Water should be applied at a rate that does not cause significant waste or soil erosion.

An examination of a farmer's irrigation water management practices should answer the following questions:

1. Is irrigation needed?
2. What is the soil moisture deficiency?
3. How much water is being applied?
4. Is irrigation causing erosion?
5. How uniformly is the applied water spread over the field?
6. How much of the water is infiltrated into the soil?

The first two questions are interrelated. A knowledge of the soil moisture deficiency (amount of water needed to refill the root zone to field capacity) is necessary to determine whether irrigation is needed. Therefore, they may properly be considered together.

Need for Irrigation and Amount to Apply

The amount of moisture remaining in the root zone and the need for irrigation may be determined by using any of the instruments or methods described previously under the heading of "Methods of Measuring or Estimating Soil Moisture."

The soil moisture deficiency also can be estimated roughly from a knowledge of the pattern of consumptive use by the particular crop, if the number of days since the last irrigation is known. For example, in an area where the irrigation guide indicates that the peak period consumptive use rate of a particular crop is about 0.8 cm (0.3 in) per day during a hot dry period, the average soil moisture deficiency would be about 8 cm (3 in) some 8 or 10 days after the last irrigation.

During periods of more moderate weather conditions, the moisture deficiency would not be expected to be so great. These kinds of estimates cannot be precise, but they are useful in checking the reasonableness of the estimates made by the soil sampling procedure outlined earlier.

The question, "Is irrigation needed?", cannot always be answered precisely. Most crops should be irrigated before more than about half of the available moisture in the crop root zone has been used.

Some crops are thought to do better at higher moisture levels (less moisture deficiency at time of irrigation). Therefore, irrigation may be needed well before half of the available water has been used. Generally, one may consider that the need for irrigation is doubtful for any crop until the soil moisture deficiency approaches one-third of the available moisture-holding capacity of the crop root zone. Special-purpose irrigations, such as for seed germination, are exceptions to this general rule.

Most crops have a critical growth period during which a high moisture level must be maintained to obtain high-quality yields. This critical period generally is during the blooming or fruiting stage.

In determining the need for irrigation, the possibility that some parts of the field may be drier than other parts should not be overlooked. Sometimes, because of poor distribution of irrigation water, the soil moisture deficiency is considerably greater in one part of the field than in another part. Also, the soil in one part of the field may have a lower available water capacity than the soils in another part. The moisture in one soil might be depleted to the 50-percent level long before the other soils approach that level. If such critical areas are of significant size, the decision to irrigate should be based on the available water in the drier areas.

Amount Applied

The amount of water required to refill the root zone (net irrigation requirement) usually is expressed in centimeters of depth. For ease in making comparisons, the amount of water actually delivered onto the field should be calculated in the same terms.

Irrigation water deliveries usually are calculated in terms of the rate of flow. The commonly used units of flow are liters per second (L/s) and cubic meters per second (m^3/s). The miner's inch (M.I.) is an old flow unit that is still used in some Western

States. It is the quantity of water that will flow through an orifice 1 in^2 under stated head, which varies from 4 to 6½ in. in different localities. Another unit sometimes used is million gallons per day (mgd).

Rate of flow is a volume delivered in a given time interval. If a time interval is specified, flow units can be converted to volume units. For example, a flow of 1 ft^3/s (flow rate) for 1 hr (time interval) will deliver 3,600 ft^3 (volume) of water. If this volume is spread evenly over an area of 1 acre (43,560 ft^2), the depth will be 0.083 ft (36,000/43,560), and the volume would be 0.083 acre-ft. This volume is equal to $0.083 \times 12 = 0.99$ acre-in. For practical use in the field, the volume can be considered to be 1 acre-in.

The above conversion of flow rate to volume is the basis for a handy formula that should be known and well understood by all irrigators and irrigation technicians:

28 L/s for 1 hr = 1 ha-cm
(1 ft^3/s for 1 hr = 1 acre-in

If flows are measured in cubic feet per second, gallons per minute, miner's inches, or million gallons per day, they can be converted to equivalent liters per second by using the following approximate relationships:

28 L/s = 1 ft^3/s
= 450 gal/min
= 38.4 M.I. in Colorado
= 40 M.I. in Arizona, Montana, Nevada, northern California, and Oregon
= 50 M.I. in Idaho, Kansas, Nebraska New Mexico, North Dakota, South Dakota, southern California, Utah, and Washington
= 0.65 mgd
= 0.028 m^3/s

After the volume of water delivered onto a field has been computed in terms of hectare-centimeters (acre-inches), it is a simple matter to calculate the equivalent average depth throughout the field. Divide the hectare-centimeters (acre-inches) by the number of hectares (acres) covered. Thus, 5 ha-cm (5 acre-inches) spread over an 0.8-ha (2 acre) field is equal to an average application depth of 6.3 cm (2.5 in), or

$$d\ (cm) = \frac{Q\ (ha\text{-}cm)\ (per\ hr) \times T\ (hr)}{A\ (ha)}$$

$$d\ (in) = \frac{Q\ (ft^3/s)\ or\ acre\text{-}in\ (per\ hr) \times T\ (hr)}{A\ (acre)}$$

Three variables must be known to compute the average depth of water applied on a field: (1) the size of the irrigation stream, (2) the time water is run onto the field, and (3) the area of the field. These variables do not consider the surface outflow. The following examples illustrate the computation procedure:

Example 1

Given:

Stream size	= 112 L/s (4 ft^3/s)
Irrigating time	= 10 hr
Field area	= 3.2 ha (8 acres)

Find the average depth applied:

Solution:

(Metric)	(English)
28 L/s for 1 hr = 1 ha-cm	1 ft^3/s for 1 hr = 1 acre-in
28 L/s for 10 hr = 10 ha-cm	1 ft^3/s for 10 hr = 10 acre-in
112 L/s for 10 hr = 40 ha-cm	4 ft^3/s for 10 hr = 40 acre-in

$$\frac{40\ ha\text{-}cm}{3.2\ ha} = 12.5\ cm\ applied$$

$$\frac{40\ acre\text{-}in}{8\ acres} = 5\ in.\ applied$$

Example 2

Given:

Stream size	= 24 L/s (375 gal/min)
Irrigating time	= 12 hr
Field length	= 201 m (660 ft)
Field width	= 50 m (165 ft)

Find the average centimeters (inches) depth applied:

Solution:

(Metric)	(English)
24 L/s for 1 hr = 0.84 ha-cm	375 gal/min/450 = 0.84 ft^3/s
24 L/s for 12 hr = 10 ha-cm	0.84 ft^3/s for 1 hr = 0.84 acre-in
201 m × 50 m = 10,050 m^2	0.84 ft^3/s for 12 hr = 10 acre-in
10,050 m^2/10,000 = 1 ha	660 ft × 165 ft = 108,900 ft^2
	108,900 ft^2/43,560 = 2.5 acres

$$\frac{10 \text{ ha-cm}}{1 \text{ ha}} = 10 \text{ cm applied}$$

$$\frac{10 \text{ acre-in}}{2.5 \text{ acres}} = 4.0 \text{ in. applied}$$

Example 3

Given

Stream size	= 68 L/min (18 gal/min) (average per furrow)
Irrigating time	= 24 hr
Field length	= 442 m (1,450 ft)
Furrow spacing	= 0.91 m (3 ft)

Find the average depth applied:

Solution:

(Metric)	(English)
68 L/min/60s = 1.13 L/s	18 gal/min/450 = 0.04 ft^3/s
1.13 L/s for 1 hr = 0.04 ha-cm	0.04 ft^3/s for 1 hr = 0.04 acre-in
1.13 L/s for 24 hr = 0.96 ha-cm	0.04 ft^3/s for 24 hr = 0.96 acre-in
442 m × 0.914 m = 404 m^2	1,450 ft × 3 ft = 4,350 ft^2
404 m^2/10,000 = 0.04 ha	4,350 ft^2/43,560 = 0.1 acre

$$\frac{0.96 \text{ ha-cm}}{0.04 \text{ ha}} = 24 \text{ cm applied}$$

$$\frac{0.96 \text{ acre-in}}{0.1 \text{ acre}} = 9.6 \text{ in. applied}$$

Example 4

Given:

Stream size	= 21 L/min (5.5 gal/min) (average per sprinkler)
Irrigating time	= 11.5 hr
Lateral spacing	= 15.24 m (50 ft)
Sprinkler spacing	= 9.15 m (30 ft)

Find the average inches of depth applied:

Solution:

(Metric)	(English)
21 L/min/60 = 0.35 L/s	5.5 gal/min/450 = 0.012 ft^3/s
0.35 L/s for 1 hr = 0.012 ha-cm	0.012 ft^3/s for 1 hr = 0.012 acre-in
0.35 L/s for 11.5 hr = 0.138 ha-cm	0.012 ft^3/s for 11.5 hr = 0.138 acre-in
15.24 m × 9.14 m = 139 m^2	50 ft × 30 ft = 1,500 ft^2
139 m^2/10,000 = 0.014 ha	1,500 ft^2/43,560 = 0.034 acre

$$\frac{0.138 \text{ ha-cm}}{0.014 \text{ ha}} = 10 \text{ cm applied}$$

$$\frac{0.138 \text{ acre-in}}{0.034 \text{ acre}} = 4 \text{ in. applied}$$

In all of the examples where the flow rate is given in terms of liters per second (gallons per minute), the general form of the equation for depth (d) in centimeters (inches) is as follows:

$$d \text{ (cm)} = \frac{\dfrac{\text{flow (L/s)} \times \text{time (hours)} \times 28 \times \text{length (m)} \times \text{width (m)}}{}}{10{,}000 \text{ m}^2}$$

$$d\ (in) = \frac{\text{flow (gal/min)} \times \text{time (hours)} \times 450 \times \text{length (feet)} \times \text{width (feet)}}{43{,}560}$$

$$d\ (cm) = \frac{\text{flow (L/s)} \times \text{time (hours)} \times 10{,}000}{\text{length (m)} \times \text{width (m)} \times 28}$$

$$= \frac{\text{flow (L/s)} \times \text{time (hours)} \times 357.14}{\text{length (m)} \times \text{width (m)}}$$

$$d\ (in) = \frac{\text{flow (gal/min)} \times \text{time (hours)} \times 43{,}560}{\text{length (feet)} \times \text{width (feet)} \times 450}$$

$$= \frac{\text{flow (gal/min)} \times \text{time (hours)} \times 96.8}{\text{length (feet)} \times \text{width (feet)}}$$

Since 28 L/s flowing 1 hr is not exactly 1 ha-cm, the above equation for d is not exact. For exact conversions, the factor 357.14 shown above should be 357.7. The conversion equation is usually shown as:

$$d\ (cm) = \frac{\text{sprinkler discharge (L/s)} \times \text{hours} \times 357.7}{\text{lateral spacing (m)} \times \text{sprinkler spacing (m)}}$$

$$d\ (in) = \frac{\text{sprinkler discharge (gal/min)} \times \text{hours} \times 96.3}{\text{lateral spacing (ft)} \times \text{sprinkler spacing (ft)}}$$

Thus, for Example 4, the depth applied would be computed as:

$$d\ (cm) = \frac{0.35 \times 11.5 \times 357.7}{15.24 \times 9.14} = 10\ \text{cm}$$

$$d\ (in) = \frac{5.5 \times 11.5 \times 96.3}{50 \times 30} = 4\ \text{in}$$

Since lateral spacing multiplied by sprinkler spacing is just another way of saying length multiplied by width (equals area), the sprinkler conversion equation can be used for all situations where the flow rate is given in terms of liters per second (gallons per minute). Example 2 can be used as an illustration.

$$d\ (cm) = \frac{24 \times 12 \times 357.7}{20 \times 50} = 10\ \text{cm}$$

$$d\ (in) = \frac{375 \times 12 \times 96.3}{660 \times 165} = 4\ \text{in}$$

In furrow irrigation work, the rate of flow as measured in individual furrows often is converted to average depth as follows:

$$d\ (cm) = \frac{\text{L/m flow per 100 m of furrow length} \times \text{hours}}{\text{furrow spacing in meters}}$$

$$d\ (in) = \frac{\text{gal/min flow per 100 ft of furrow length} \times \text{hours}}{\text{furrow spacing in feet}}$$

This is equivalent to:

$$d\ (cm)\quad \frac{\text{L/min} \times \text{hours} \times 6}{\text{length (m)} \times \text{width (m) (or spacing)}}$$

$$d\ (in) = \frac{\text{gal/min} \times \text{hours} \times 100}{\text{length} \times \text{width (or spacing)}}$$

While this is less accurate than the other conversion methods discussed, the error is slightly less than 4 percent.

Field Application Efficiency

The field application efficiency is determined by dividing the net amount of water needed to refill the root zone by the amount of water actually applied onto the field. Thus, if the net amount of water needed is 8.1 cm (3.2 in) and the amount applied is 12.7 cm (5.0 in), the field efficiency is 64 percent (8.1 cm/12.7 cm = 0.64 or 3.2 in/5.0 in = 0.64).

High efficiency does not always mean good irrigation. The water may not have been distributed evenly over the field, or the amount applied may not have been enough to bring the root zone up to field capacity. On the other hand, low field efficiency usually means poor use of water and indicates a need for a careful check of the water management practices being used.

No clear distinction exists between high and low efficiencies. It is impossible to irrigate at an efficiency of 100 percent. Yet, the further irrigation departs from this ideal, the more costly it becomes from the standpoint of water use and the more apt it is to damage the soil. In general, all water applications should be made at the highest efficiency level that is practical and feasible. State irrigation guides give the percent efficiency that the average irrigator can expect to obtain if good management practices are used in a properly designed and developed system.

Uniformity of Application

Adequate irrigation refills the planned root zone storage capacity throughout the field. To do this with a minimum amount of loss to deep percolation, the water must spread uniformly over the field so that each part of the field will have the same opportunity time to take in water. Opportunity time is the length of time that irrigation water is available at the surface for infiltration into the root zone.

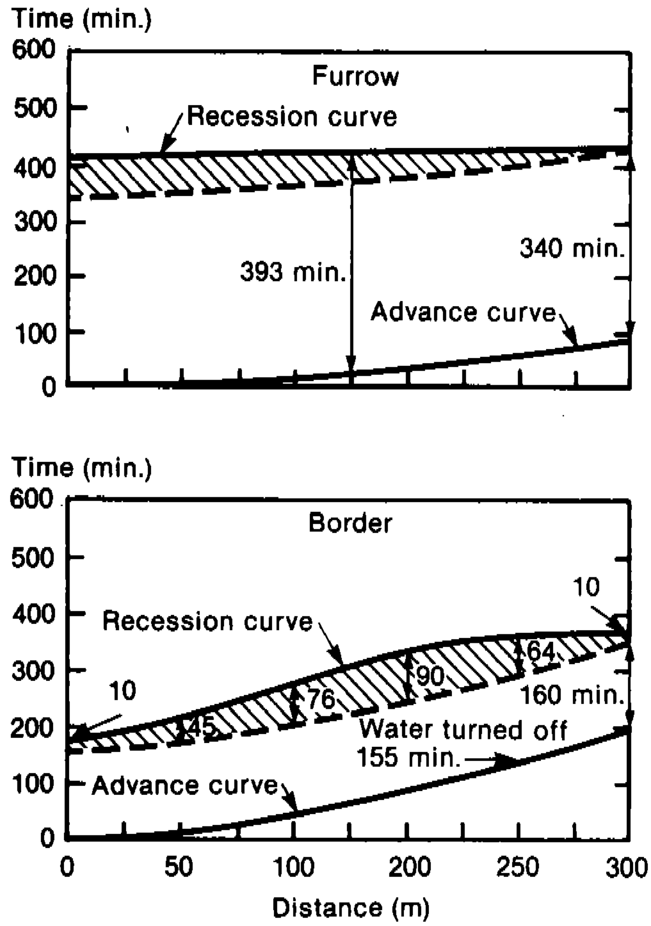
The best way to determine whether a field has received adequate irrigation is to check the soil moisture conditions a day or so after irrigating. Dig or auger into the soil at representative locations to see if the root zone has been brought up to field capacity. If dry layers or areas are found, irrigation was not complete or the water was not spread evenly.

For surface methods of irrigation, the uniformity of water distribution can be checked by determining how long the water is on the surface at various points along the length of the run. If this length of time is about the same at all points and the soils are similar, it can be assumed that the same amount of water has infiltrated the soil in each part of the field. Usually, a check on the opportunity time at all points along the length of the run can be determined by observing the time water reaches and recedes from selected points. These data are used to plot advance and recession curves as shown in figures 15-4 and 4A. The vertical distance between the advance curve and the recession curve at any point along the length of the run is the "intake opportunity time" at that point. The opportunity time at all points should be sufficient to permit the desired amount of water to infiltrate the soil.

Water distribution in furrows. Since the volume of water contained in a furrow as temporary surface storage at the end of irrigation usually is relatively small, furrow recession curves are nearly flat. In other words, the water stops flowing at the lower end of the furrow within a few minutes after the water is turned off (figures 15-4 and 4A). Therefore, to obtain good water distribution, the "advance" period should be as short as possible.

Figure 15-4

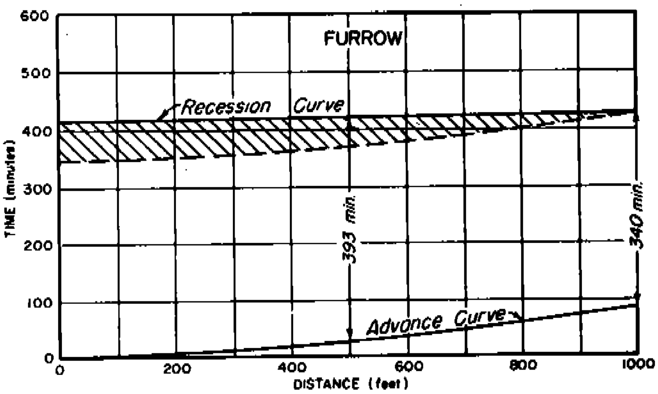
Sample Advance and Recession Curves



Figures 15-4 and 4A show an irrigation that meets the above criterion. In this example an intake opportunity time of 340 min is required to put the desired amount of water into the soil. Opportunity time at any point along the furrow is the time between the advance and recession curves. It took 85 min for the furrow stream to reach the end of the run. The water was turned off 410 min after the start of irrigation and stopped flowing in the lower end of the furrow 15 min later.

The required intake opportunity time is shown by the broken line drawn parallel to the advance curve. The shaded area above the broken line indicates the excess intake opportunity time (deep percolation time). At the upper end of the run the deep percolation time is 70 min (410 − 340 = 70). In the center it is 53 min (393 − 340 = 53). There is no deep percolation time at the lower end of the run in this example.

The weighted average deep percolation time is 44 min (70/2 + 53 + 0 = 88; 88/2 = 44). This is 13 percent of the required 340 min of intake opportunity time. However, because intake rates decrease with time, the average depth of water lost to deep percolation will be less than 13 percent of the depth needed to refill the soil profile.



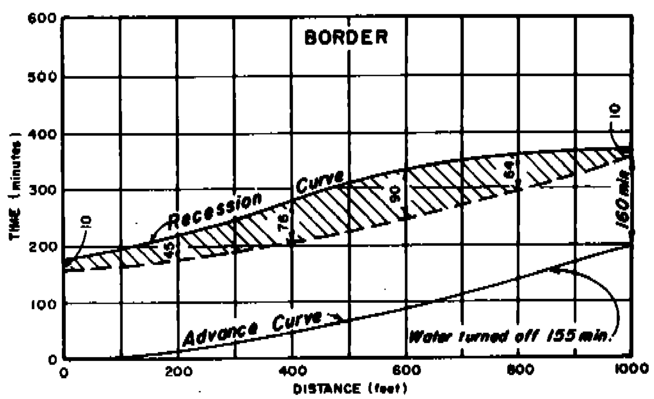


Figure 15-4A—Sample advance and recession curves (in feet).

Water distribution in graded borders. In graded border irrigation, a relatively large volume of water is in temporary storage on the surface of the border strip when the water is turned off. In some cases, the water may amount to more than half of the total volume run onto the strip. This water continues to be absorbed into the soil, and some of it moves on down the strip to irrigate the lower end. The movement of water on the surface greatly prolongs the recession time at the lower end of the field (figures 15-4 and 4A).

If the irrigation stream is properly adjusted for the intake characteristics of the soil, the required depth of application, and the border strip size, the recession curve will roughly parallel the advance curve. The two curves are said to be "balanced." Even under the most ideal conditions, however, the two curves are never exactly parallel. Therefore, to provide adequate intake opportunity time at all points along the length of the run, there will be excess opportunity time at some points. Usually, a good distribution of water can be achieved if the water is nearly across the field (close to the cutoff point) by the time the volume needed to fill the root zone has been released into the border strip.

Figures 15-4 and 4A show an irrigation that meets this criterion. In this example, 160 min is required to put the desired amount of water into the soil. With the stream size used, the needed volume of water should be delivered onto the strip in 125 min. At the end of this time, the stream had advanced 229 m (750 ft). It was still 76 m (250 ft) from the lower end. To provide sufficient intake opportunity time at the upper end of the run and furnish enough water to complete the irrigation at the lower end, the flow was continued for an additional 30 min.

The required intake opportunity time is shown by the broken line drawn parallel to the advance curve. The shaded area above the broken line indicates the excess intake time when deep percolation will occur. In this example the deep percolation time ranges from about 90 min in the middle part of the run to 10 min at both the upper and lower ends. The weighted average deep percolation time is about 60 min ($\frac{10}{2}$ + 45 + 76 + 90 + 64 + $\frac{10}{2}$ = 285; 285/5 = 57). The weighted average intake opportunity time, then, is 217 min 160 + 57 = 217). This is approximately 36 percent more time than required to infiltrate the soil with the desired amount of water. The total amount of water delivered on the border was only 24 percent more than that required to refill the root zone (30 min/125 min = 0.24). With the distribution shown, deep percolation could not exceed this amount. Also, some runoff occurred from the end of the border.

Water distribution in level borders. In level border irrigation, the amount of water required to provide the desired depth of water is ponded on a diked area of level, or nearly level, land until it can infiltrate the soil. Like graded border irrigation, a large volume of water is in temporary storage on the surface of the strip at the time the water is turned off. However, level borders have no grade to cause this water to move toward the lower end of the run. Therefore, the recession curve is flat. To obtain good water distribution, the advance curve, too, should be made as flat as possible.

Level borders usually are designed to have an advance time of approximately one-fourth of the required intake opportunity time. In some cases, however, good distribution and acceptable efficiencies can be obtained where the time required for the water to fully cover the strip is considerably greater than one-fourth of the time required for the desired infiltration.

For all surface methods of irrigation, the uniformity of application greatly depends on the size of the irrigation stream. On a given field, a large stream will advance down the run in less time than a smaller stream. Therefore, if the intake opportunity time is too long at the upper end of a run and too short at the lower end, the stream size should be increased to flatten the advance curve. If the stream cannot be increased, the border width may have to be decreased the next time borders are installed.

There is a limit to the size of stream that can be used. The stream must be kept within the erosion limits of the site. Also, it must not be so large that it will overtop the furrows or the border ridges. If the stream size cannot safely be increased enough to provide good water distribution, the length of the run should be shortened.

In graded border irrigation the intake opportunity time may be too short at the upper end of the run and too long at the lower end. If so, the stream size should be reduced. This reduction will increase the time needed to deliver the required volume of water onto the border strip, and thus increase the intake opportunity time at the upper end of the run. Also, the smaller stream will require more time to advance down the border, and this will reduce the intake opportunity time at the lower end of the run.

Tail-water recovery. To obtain high efficiencies with surface irrigation, it is generally necessary to permit some surface runoff at the lower end of the field, even under good management with cutback streams. In order to save this water and prevent downstream damage, tail-water recovery systems are becoming a common practice. Also, many cutback systems require a large amount of labor, so many farmers are replacing the cutback technique with some type of tail-water recovery. The tail-water recovery system usually consists of collecting the runoff water in a tail ditch, which diverts it to a lower field for reuse or to a sump or storage basin. The stored water in the sump is then pumped through pipelines to a higher elevation for reuse.

Water distribution with sprinklers. The uniformity of water distribution on a sprinkler-irrigated field can be checked by measuring the discharge of the first and last sprinklers on the lateral lines. Also, as the discharge of sprinklers is directly proportional to the square root of their nozzle pressure, the uniformity can be checked by measuring the pressure at the first and last sprinklers. Thus, if pressure is 350 kPa (50 psi) at the first sprinkler and 280 kPa (40 psi) at the last sprinkler, the pressure at the first sprinkler is 1.25 times that at the last sprinkler. The discharge of the first sprinkler is the square root of 1.25 times the discharge of the last sprinkler. The square root of 1.25 is 1.12. Therefore, the first sprinkler applies 12 percent more water than the last sprinkler.

The rate at which water is being delivered to a field through sprinkle irrigation can be determined by measuring or estimating the discharge of one or more individual sprinklers. Volumetric measurements may be made by placing a hose or small tube over the sprinkler nozzle to direct the water into a container of known size, such as a 10- or 20-L (3- or 5-gal) bucket. The time required to fill the container is measured with a stopwatch. After the time required to collect a given volume has been determined, the flow rate can be computed from the following formula:

$$\text{Flow (L/min)} = \frac{60 \times \text{capacity of container in liters}}{\text{number of seconds to fill}}$$

$$\text{Flow (gal/min)} = \frac{60 \times \text{capacity of container in gallons}}{\text{number of seconds to fill}}$$

Thus, if 33 seconds are required to fill a 10-L (3-gal) bucket, the flow rate is 18.2 L/min (5.4 gal/min).

$$Q = \frac{60 \times 10}{33} = 18.2 \text{ L/min}$$

$$Q = \frac{60 \times 3}{33} = 5.4 \text{ gal/min}$$

Since sprinkler-nozzle discharge is related to the pressure head at the nozzle, the flow rate can be reasonably estimated if the pressure is known. Most sprinkler manufacturers' catalogs contain tables showing the discharge of their sprinklers as related to pressure. For reliable estimates the pressure must be measured at or close to the nozzle.

In some instances it may be feasible to determine the discharge of each sprinkler on a lateral. The values should be averaged to determine the average rate of application. One way of doing this is to measure the discharge of the first and last sprinkler on the lateral. The average discharge for all the sprinklers can then be computed as the discharge of the last sprinkler plus one-fourth of the difference between the first and last sprinklers.

Sometimes, because of topographic conditions, the minimum pressure may not be at the last sprinkler. If the sprinkler lateral runs downslope, the minimum pressure may be at the first sprinkler. Where sprinkler laterals are not laid out on a nearly uniform grade, the pressure or discharge should be measured at the high and low spots as well as at the end sprinklers.

The volumetric measurements will indicate the overall distribution of water across the field. The uniformity of water distribution in the effective area of an individual sprinkler can be best determined by setting out a pattern of catch cans and measuring the depth of water caught. The cans should be set in a symmetrical pattern across the lateral between two sprinklers. The cans should be about 1.5 m (5 ft) apart where the sprinklers' spacing is less than 9 m (30 ft). Three-meter (10-ft) spacing is adequate where sprinklers are 9 m (30 ft) or more apart. The procedure for making water distribution pattern tests is explained in Agricultural Handbook No. 82, "Methods for Evaluating Irrigation Systems."

Usually, there is little need for making a distribution pattern test unless soil moisture tests after an irrigation or the appearance of the crop indicates uneven water distribution. If sprinkler spacing and nozzle pressures meet the criteria given in Chapter 11, Section 15, of the National Engineering Handbook, distribution patterns usually will be satisfactory.

Water distribution in trickle systems. Since trickle systems are normally designed to wet only a part of the plant rooting area, it is very imporant that they be checked periodically for adequate water application and distribution. Performance is evaluated by gathering and analyzing data on such items as (1) duration, frequency, and sequence of irrigation cycle; (2) moisture deficits in the wetted area; (3) rate of discharge and pressure at selected emission points; (4) changes in emission discharge rates with time; (5) percentage of soil volume wetted; (6) location and uniformity of emission points with respect to the plants; and (7) losses of pressure at filters. The procedure for making field evaluations of trickle systems is given in Chapter 7, Section 15, National Engineering Handbook.

Water distribution in center-pivot systems. Center-pivot systems are unique because the speed and the rate of water application must increase as the distance from the pivot increases. This increase is accomplished by increasing the size of sprinkler nozzles, decreasing the spacing of sprinklers, or both. Therefore, there is no set application rate for these systems. If they are designed, installed, and operated properly, the depth of application will be nearly uniform over the length of the systems.

The operating characteristics of these types of systems can be checked by determining the gross application and application rate at a point toward the outside end of the lateral. The application rate will decrease toward the pivot and, therefore, will be satisfactory if the application rate at the outer end is within the soil intake capabilities.

The water distribution along the length of a center-pivot system can be checked by setting a line of evenly spaced measuring cans (or gages) ahead of the system, allowing the system to move over them, and measuring the depth of water caught in each can. If the depths measured are uniform, the average of all measured depths represents the amount applied to the field per revolution. If the depths of water caught differ widely, especially between the inner and outer parts of the system, the average depth applied will need to be calculated using weighted measurements. This can be done by assigning factors to multiply each measurement by, depending on the distance of the can from the pivot. If the cans are evenly spaced, use a factor of one (1) for the first can, two (2) for the second can, three (3) for the third can, and so on. Total the results of these multiplications and divide by the sum of the can numbers (1 + 2 + 3, etc.) to obtain the average depth applied to the field per revolution of the system.

Irrigation with sprinkle and level border or level furrow methods often produces no runoff. In such cases the average depth of water applied onto the field is also the average depth that infiltrates the soil. When surface runoff does occur, however, it must be measured to determine the depth of water retained on the field.

The average depth of water that infiltrates the soil during irrigation can be best determined by subtracting the volume of water lost through surface runoff from the total volume applied to the field. This volume divided by the area of the field will be the average depth of water infiltrated.

On many fields, surface runoff rates can be measured periodically in existing drainage or waste-water ditches to furnish adequate data for the computation of runoff volume. Where site conditions make it infeasible to collect and measure runoff from an entire field, measurements of runoff rates from representative individual furrow or border strips may be used in estimating total runoff.

Runoff rates usually increase as intake rates decrease. Therefore, to determine the volume of surface runoff, the rate of runoff usually must be measured at intervals throughout the runoff period. Runoff rates are converted to runoff volumes by use of the conversion formula: 28 L/s flowing 1 hr equals 1 ha-cm (1 ft^3/s flowing 1 hr equals 1 acre-in). The procedure is the same as explained previously for computing the amount of water applied to the field. With changing flow rates, however, the computation must be made in steps. The volumes of runoff are computed for each time interval between measurements and summed to determine the total runoff. Table 15-2 shows a sample set of runoff calculations. In this example, the rate of flow onto the field is assumed to be 42 L/s (1.5 ft^3/s) throughout the 12-hr irrigation period. The total volume run onto the field, therefore, is 18 ha-cm (18 acre-in).

If a field is irrigated by surface flooding, using borders, basins, or contour ditches, cylinder infiltrometers can be used to determine the amount of water that infiltrates the soil in a given period. Figures 15-5 and 5A show an intake curve developed from cylinder infiltrometer data.

In order to use cylinder intake curves as a basis for estimating the average depth of water that infiltrates the soil, the average intake opportunity time must be known. For example, if the sample intake curve shown in figures 15-5 and 5A were developed on a bordered field that has the advance and recession characteristics illustrated by figures 15-4 and 4A, the average intake opportunity time would be 217 min (170/2 + 205 + 236 + 250 + 224 + 170/2 + 1085; 1085/5 = 217). The weighted average depth of water that infiltrated the soil would be 12.5 cm (5 in).

Figures 15-4 and 4A for borders also show a minimum intake opportunity time of 170 min, which, according to the intake curve, is more than sufficient to have 10 cm (4 in) of water infiltrate the soil. Assuming this is the depth of water needed to refill the soil profile, the average deep percolation loss would be 2.5 cm (1.0 in).

In a field irrigated by furrows or corrugations, the average depth of water that infiltrates the soil can be estimated from a measurement of the instantaneous furrow intake rate. To use this procedure, the furrow intake rate should be determined by inflow-outflow measurements of individual furrows or of a group of furrows. The measurements should be made near the end of the irrigation period, generally sometime in the last quarter of the period. The difference between the inflow rate and the outflow rate will represent the rate of furrow intake. The furrow intake rate should be expressed in terms of liters per minute per 100 m of furrow (gallons per minute per 100 ft of furrow). It can then be converted to an equivalent field intake rate, in centimeters per hour (inches per hour), by dividing by the furrow spacing, in meters (feet).

The field intake rate thus determined can be considered the instantaneous rate at the end of the irrigation. The rate usually changes very little during the last part of the irrigation period, so any error resulting from this assumption will be small. The average intake rate for the total irrigation, however, will include an initial period of relatively high intake rate which gradually diminishes to the instantaneous rate measured at the end of the irrigation. The difference usually will be greatest on fine-textured soils that characteristically have steep intake rate curves and least on coarse-textured soils that generally have relatively flat intake rate curves. For most soils the average rate can be approximated by multiplying the final rate by the applicable soil factor indicated in table 15-3.

Table 15-2

Computation of Runoff Volume

Clock time	Measured runoff (ft^3/s = acre-in./hr.)	Measured runoff L/s	Averge flow rate (acre-in./hr.)	Averge flow rate L/s	Time interval (hr.)	Runoff volume (acre-in.)	Remarks
08:15							Irrigation ends (inflow = 1.5ft^3/s)
10:15	0.00	0.00					Runoff starts
			0.185	5.25	0.50	0.093	
10:45	0.37	10.50					
			0.410	16.65	0.50	0.205	
11:15	0.45	12.80					
			0.490	13.95	1.00	0.490	
12:15	0.53	15.10					
			0.585	16.65	2.00	1.170	
14:15	0.64	18.20					
			0.695	19.80	3.00	2.085	
17:15	0.75	21.40					
			0.785	22.40	3.00	2.355	
20:15	0.82	23.40					Irrigation ends
			0.410	11.70	0.25	0.102	
20:30	0.00	0.00					Runoff ends
						6.500	Total runoff

Figure 15-5

Sample Intake Curve

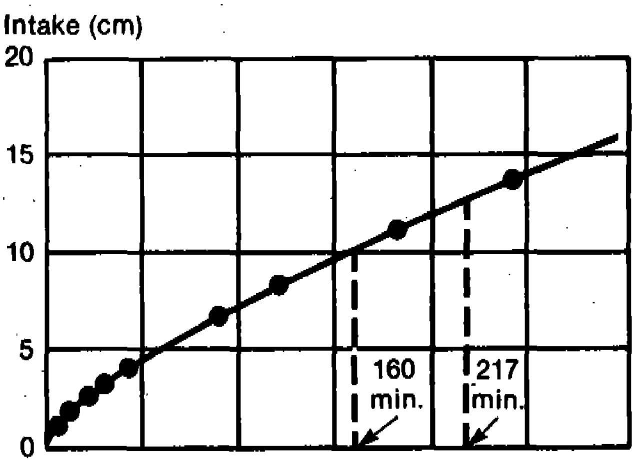


Figure 15-5a

Sample Intake Curve

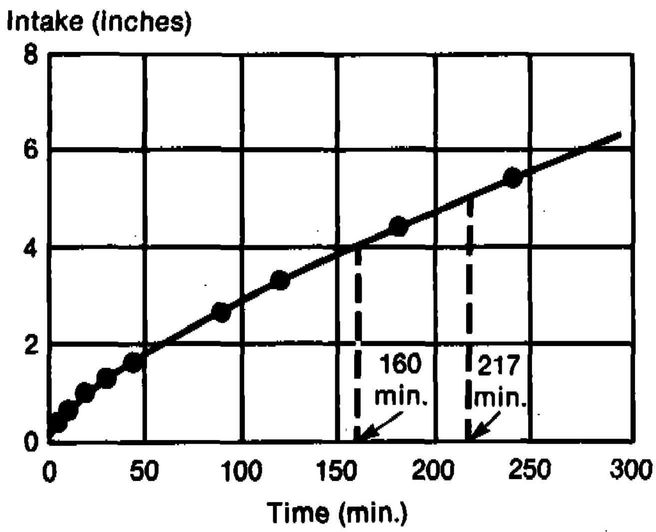


Table 15-3—Soil factors for estimating average intake rate from final intake rate

Soil texture	Soil factor
Fine and moderately fine clays and clay loams	1.50
Medium and moderately coarse silt loams to sandy loams	1.33
Coarse and very coarse loamy sands and sands	1.20

The average intake rate multiplied by the average intake opportunity time will equal the average depth of infiltration.

The computations used to estimate the average depth of infiltration (d) were derived from measurements of the instantaneous rate of intake and are illustrated in the following example:

Assume:

Moderately coarse-textured soil	(factor	= 1.33)
Furrow spacing		= 0.91 m (3.0 ft)
Total irrigating time		= 8.0 hr
Average intake opportunity time		= 6.9 hr

Intake rate measurements made on three representative furrow sections about 7 hours after start of irrigation.

Measurements and computations:

	Furrow number		
(Metric)	1	2	3
Inflow rate			
Sta. 0 + 00 – L/min	77.0	80.5	74.8
Outflow rate			
Sta. 0 + 61 – L/min	66.0	67.3	63.1
Intake rate			
– L/min	11.0	13.2	11.7
	Average 12.		

$$d\ (\text{cm}) = \frac{12 \times 6.9 \times 6}{61 \times 0.91} \times 1.33 = 12\ \text{cm}$$

	Furrow number		
(English)	1	2	3
Inflow rate			
Sta. 0 + 00 – gal/min	20.4	21.3	19.8
Outflow rate			
Sta. 2 + 00 – gal/min	17.4	17.8	16.7
Intake rate			
– gal/min	3.0	3.5	3.1
	Average 3.2.		

3.2/2.0 = 1.6 gal/min per 100 ft final furrow rate.
1.60/3.0 = 0.533 in. per hour final field rate.
0.533 × 1.33 = 0.71 in. per hour average field rate.
0.71 × 6.9 = 4.9 in. average intake depth.

Estimating Rates of Flow

The discussion and examples presented to illustrate procedures for evaluating irrigation water management practices have assumed that the rate of flow of the irrigation stream was known. In many cases this is true. If water is delivered from a well, the farmer usually knows the approximate discharge. Many irrigation districts and irrigation companies measure delivery flows at the farm headgate. Some farm systems have weirs or other water-measuring devices to measure the flows to specific fields. If the rates of flow are not known, however, it may be necessary to rely on estimates. Measurements of some kind usually are needed. Some of the most usable estimating procedures, such as the float method and velocity head rod for open channels and the trajectory method for pipe flow, are discussed in Chapter 3 of this manual and Chapter 9, Section 15, SCS National Engineering Handbook.

Soil Erosion

Erosion is a hazard on most irrigated lands. Any irrigation method that causes a significant amount of erosion cannot be considered satisfactory.

Serious erosion can occur even when little or no soil is removed from the field. Where surface irrigation is used, the irrigation streams are largest where they first enter the field. As they progress toward the lower end of the field, the streams are reduced by the amount of water infiltrated into the soil. Often the large streams will erode the soil at the upper end of the field but have insufficient carrying capacity at the lower end to remove the material from the field.

Soils irrigated by a surface method usually have the greatest erosion during the initial stages of irrigation. The dry surface soil, sometimes loosened by cultivation, is readily moved by the flowing water. After a short period of soaking, however, the soil settles and becomes more difficult to move. Using sprinkle irrigation, however, the erosion pattern is apt to be reversed. At the start of irrigation, the intake rate may be higher than the application rate so no runoff or erosion will occur. In the later stages of irrigation, however, the intake rate may become less than the application rate. If this occurs, the water may begin to move over the surface and cause erosion. Sprinklers should be designed and operated so that the application rate does not exceed the soil intake rate.

With surface irrigation, some soil movement can be expected. However, irrigation streams should not be so large that they cut furrow side slopes, form rills in border strips, or cause other obvious movement of soil toward or off the lower end of the field. Even though irrigation streams can be controlled to prevent erosion, measures may be needed to control erosion caused by rainfall, as discussed in the section "Relationship to Erosion Control and Drainage."

Special Problems

When evaluating irrigation water management practices, it is important that all of the circumstances, conditions, and objectives involved be carefully examined. Under some conditions the conservation use of water resources cannot be appraised adequately in terms of a computed field application efficiency. It may be necessary to evaluate the whole farm or, in some cases, an entire irrigation project or watershed area. Also, there are conditions under which a needed irrigation cannot be applied without substantial deep percolation or surface runoff. If the water is reused on the same or adjacent field and the water quality is not impaired, the surface runoff may not be undesirable. Some of the more commonly encountered problems are discussed in subsequent sections.

Irrigation at High Moisture Levels

Sometimes it is necessary to apply irrigation water when only the top few inches of soil are below field capacity. This kind of irrigation may be needed to:

1. Supply moisture for seed germination,
2. Keep the surface moist to prevent crusting on some soils, or
3. Wet the surface to reduce damage to emerging plants caused by salt accumulations.

Using surface methods of water application for such light irrigations may be very inefficient. Where only one such irrigation is needed to get a crop established, the low level of efficiency usually can be tolerated. The use of sprinklers should be considered, however, if several of these light irrigations are required. Lettuce growers in the Salinas Valley of California, for example, have found that by irrigating with sprinklers until thinning time, they can greatly reduce the amount of water needed and at the same time obtain a more uniform crop stand. After thinning time, the crop is irrigated by the furrow method. In other areas farmers have noticed distinct advantages in using sprinklers to establish grass and legume crops.

Evaluation studies of these early season, special-purpose irrigations are desirable. These studies, however, usually form a poor basis for appraising the farmer's overall irrigation water management practices since irrigation systems usually are designed for normal irrigation required after the crops have become established.

Lateral Spread of Water

Furrow spacing usually is fixed for cultivated row crops. On these fields, irrigation must be continued until an adequate lateral spread of water has been obtained. On some soils, the extended time needed for adequate wetting between furrows may result in a low application efficiency. The entire ground surface need not be wetted ("blacked out") in most cases. Usually, however, irrigation should be continued until the wetted bulbs from adjacent furrows touch, or nearly touch, at their widest point. Very little lateral spread can be expected after the water is turned off; most of the moisture movement or soil drainage will be vertical.

The problem of obtaining adequate lateral spread usually is greatest with crops planted on high ridges or beds. It is especially hard to obtain adequate lateral spread if there are also steep irrigation grades that limit the depth of flow in the furrows. Improvements often can be made by changing the irrigation layout to irrigate across the slope. The flatter irrigation grades will permit the use of furrow streams that have greater depths of flow and greater wetted perimeters. Sometimes it is even desirable to use level furrows. The increased wetted area will reduce the distance that the water has to move laterally and upward into the beds. Sometimes the lateral movement can be speeded by rolling or otherwise compacting the beds. Loose ridges or beds often have many large pore spaces. When the beds are compacted, pore size distribution is improved and capillary movement is accelerated.

Leaching

In some areas, extra water is needed to prevent the accumulation of excessive amounts of salts in the crop root zone. The process of removing these salts by the action of percolating water is called leaching. Leaching can be effective only if drainage through the root zone is possible.

Water for leaching should be applied according to a planned program. Usually, extra water for leaching need not be applied at every irrigation. Generally, a satisfactory salt balance can be maintained by making leaching applications during the nonpeak irrigation period. A need for leaching is never an adequate excuse for poor irrigation water management practices. Inefficient and poorly distributed irrigation water applications are more apt to intensify salt problems than to alleviate them. After a soil has been drained and initially leached, the amount of excess irrigation water applied to maintain a favorable salt balance should be based on the quality of the water and the salt tolerance of the crops being irrigated. This determination requires detailed analysis and should be made only by those thoroughly familiar with the leaching process.

Overall Water Resource Use

A primary objective of the Soil Conservation Service is to conserve the use of water. Conservation of water, however, is not always synonymous with high field application efficiency. There are circumstances in which applying irrigation water at very low efficiency is justified.

Suppose, for example, a farmer in the upper part of a watershed has a water supply available for diversion that far exceeds the consumptive needs of the crops. Water is spread over the fields using large but nonerosive streams so that the lower ends of the irrigation runs will have nearly as much intake opportunity time as the upper ends. The farmer stops irrigating when the water has been applied long enough to refill the crop root zone but makes no effort to minimize surface runoff. Runoff is collected in waste water ditches and returned to the stream. Field application efficiencies may average less than 50 percent; however, there is no waste of the water resources. The surface runoff is immediately returned to the stream channel where it is available for diversion by downstream users. There is no soil erosion, and water losses from deep percolation are minimized.

Situations such as that described should be fully considered in evaluating a farmer's irrigation water management practices. Always, however, one must be sure all of the pertinent factors are taken into account. Water quality, for example, is a factor sometimes overlooked. Irrigation water lost through deep percolation often is recovered in the stream as return flow. Seldom, however, is this water comparable in quality to the original stream supply. Percolating waters usually pick up some salts as they move through the soil profile. Return flows from surface runoff may also be lower in quality under some circumstances. Water management practices that result in low field application efficiencies, therefore, should be examined thoroughly before they are accepted as meeting conservation objectives.

Moisture Accounting Method for Scheduling Irrigation

Use

Moisture accounting is a proven useful method for scheduling irrigations in humid areas by providing a running account of available moisture in the effective root zone. It requires a daily recording of rainfall, estimated evapotranspiration, net irrigation amounts, and moisture balance methods that depend upon the accuracy with which available moisture-holding capacities of the soil, rainfall, net irrigation amounts, and evapotranspiration values are determined. The same degree of accuracy should be used in determining each of these factors. Therefore, use of the method is limited to those areas where reliable values can be obtained. In humid areas, occasional rains refill the root zone to field capacity, thereby preventing an accumulation of errors that might affect the accuracy of the method.

Of all the factors mentioned in the previous paragraph, perhaps the most critical to determine is daily evapotranspiration. Values of this factor must be reliable, yet relatively simple to determine by the average irrigator. A compromise is required between accuracy and the practical limitations imposed by field conditions.

In the Northeastern United States the relationship of evapotranspiration to daily hours of sunshine and stage of crop growth has been satisfactorily established. Generalized tables are available that provide daily adjustments to evapotranspiration based on observations of sunshine hours. New tables and different adjustment factors, or possibly an entirely new kind of estimating procedure, will be needed in other areas of the United States.

Basic Principles

The moisture accounting method is based on two principles:

1. When an adequate supply of available moisture is present in the effective root zone, the rate of consumptive use by a given crop depends primarily on the stage of growth and climatological conditions.
2. When the moisture content of the effective root zone is known at any given time, the moisture content at any later time can be computed by crediting moisture gained from effective rainfall or irrigation and subtracting the daily moisture withdrawals during the elapsed time.

Conditions for Use

To apply the basic principles, the following are necessary:

1. Soils with good internal and surface drainage.
2. An adequate irrigation system and water supply.
3. Daily consumptive use values for the crop.
4. Sufficient plant population.
5. Accurate total available moisture values.
6. A knowledge of the effective root zone of the crop.
7. Measurement of effective rainfall and irrigation applications at the site.
8. Occasional soil moisture checks to verify the account, especially during the critical periods of crop growth and for inexperienced users.

Equipment Required

1. Wedge-shaped plastic rain gage with a 50- by 62.5-mm (2- by 2½-in) minimum top opening.
2. Record book.
3. Means of measuring average application rate of sprinklers or the application amount by surface methods.

Installation and Reading of the Rain Gage

The rain gage should be set on a post located in the field or in an open area adjacent to the field being irrigated. The distance of the gage from nearby obstructions that might affect the catch, such as trees or buildings, should be at least twice the height of the obstruction. The gage should be about 1 m (3 ft) above ground level and its top should be at least 8 cm (3 in) above the top of the post.

The amount of rainfall in the gage should be read at the lowest point of the water surface. The reading should be made as accurately as possible. After the rainfall amount has been recorded, the gage should be emptied and reset in its holder.

Use of the Moisture Balance Sheet for Scheduling Irrigation

A moisture balance sheet for scheduling irrigation is shown in tables 15-4 and 4A. Although the example is for a crop of early potatoes, the same procedure applies to other crops and soils. The example is from an account for an entire growing season. The overall procedure for using the balance sheet is as follows:

1. Record all available pertinent information in the heading. (See table 15-4 or 4A.)
2. Determine the total available moisture-holding capacity of the effective root zone and record it in the heading of the form. Use one of the following sources:
   a. Field testing. Field-measured values of moisture percentage at field capacity and wilting point should be used whenever possible. The moisture percentage at wilting point should be taken from soil characteristic reports on representative soils or estimated as described later in the section "Moisture Percentage at Wilting Point."
   b. Irrigation guides.
   c. Other publications giving characteristics of local soils.
3. Determine the balance when irrigation is to begin. The value frequently used is 50 percent of the total available moisture in the effective root zone, but the value should be selected to suit site conditions and the operational plan. Irrigation must begin when the soil moisture is at a level that will permit the completion of the irrigation cycle before the available moisture is seriously depleted. Some farmers may desire a starting balance that provides for the maintenance of moisture above 50 percent. Others may choose a starting balance that permits irrigation applications of a stated amount, that is, about a 2.5-cm (1-in) net irrigation at each application.

Beginning Moisture Balance

On a date near the normal planting date or start of growth for perennial crops and tree fruits, when the field is at field capacity, enter the total available moisture-holding capacity of the soil in the daily balance column (6) of the Moisture Balance Sheet (see table 15-4 or 4A).

1. If the moisture percentage at field capacity has been determined previously for the field, measure the current moisture percentage to provide an accurate value for starting the moisture balance sheet.
2. If no field measurement of moisture percentage at field capacity is available, begin the account with an estimated value. At the first opportunity after adequate rain or irrigation obtain the field capacity moisture percentage and correct the account accordingly.
3. If at the time of plant emergence, a week or more has passed since the soil was at field capacity and tillage and seeding operations have ensued, estimate the moisture balance as being about 1.3 cm (0.5 in) below the field capacity value.
4. Estimate early season moisture losses before plant emergence by using an evaporation rate from the soil surface at 0.08 cm (0.03 in) per day for the first week after the soil has been wetted to field capacity. Use an evaporation rate of 0.08 cm (0.03 in) per week for the remaining period. For bare or tilled soil conditions during May or later in the season when the mean daily temperature is above 17 °C (63 °F), estimate evaporation from the top 15 cm (6 in) of moist soil as averaging 0.3 cm (0.1 in) per day for the first 5 days from a depth of 0.13 cm (0.05).
5. Estimate moisture losses by measuring the depth of the dried surface layer and multiplying this depth by the available water-holding capacity of the soil per centimeter (inch) of depth.
6. When a sod or cover crop is plowed under shortly before the planting date, the moisture balance may be considerably less than field capacity. Unless total rainfall between plowing and planting has brought the moisture level to field capacity or above, measure the moisture content of the soil at the start of recordkeeping.

Determining End-of-Day Moisture Balance

For end-of-day moisture accounting:

1. Record the hours of observed daily sunshine in column 2. The hours of sunshine for any day will vary according to cloud cover and the length of day.
2. Estimate evaporation from the soil surface, or following transplanting or plant emergence by selecting from an appropriate table of estimated values of daily evapotranspiration, such as table 15-5, the daily moisture use value for the observed weather condition and the stage of crop growth. Enter this value in column 3. This sample table was developed for annual crops, based on climatic, crop, and soil conditions found in Northeastern United States.

Table 15-4—Moisture balance for scheduling irrigation

Month March 19 79

Farm I. M. Manager
County Sussex
Field 2

Soil type Sassafras sl
Crop Early Potatoes Root depth 46 cm
Available Moisture Capacity 6.1 cm
Irrigate when balance is 3.5 cm

Date	(1) Days after transplanting or emergence	(2) Observed sunshine hours	(3) Estimated daily evapotranspiration (ET) cm/day	(4) Rainfall cm	(5) Net irrigation application cm	(6) Daily balance cm	(7) Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
			Balance Brought Forward			Note: Use ET Table for 90-day growing season	
1							
2							
3							
4							
5				3.20		6.10	Field capacity (FC)
6							
7							
8							
9							
10							
11							
12							Planting date
13							
14							
15							
16		11				4.83	Estimated
17		2	0	0.79		5.62	
18		1	0	1.90		6.10	Total = 7.52
19		10	0.08			6.02	
20		6	0	0.91		6.10	
21		11	.08			6.02	Evaporation, surface
22		12	.08			5.94	Evaporation, surface
23		12	.08			5.86	Evaporation, surface
24		12	.08			5.78	Plant emergence
25	1	10	.10	0.20		5.88	Less than 0.5 rain
26	2	2	.10	1.98		6.10	1.7 over FC
27	3	10	.10			6.10	Free water use
28	4	3	.10	0.71		6.10	Free water use
29	5	10	.10			6.00	
30	6	11	.13			5.87	Sprayed
31	7	10	.13			5.74	ET rate change
Totals			1.16	9.69			

Table 15-4—Moisture balance for scheduling irrigation (continued)

Month April 19 79

Farm I. M. Manager
County Sussex
Field 2

Soil type Sassafras sl
Crop Early Potatoes Root depth 46 cm
Available Moisture Capacity 6.1 cm
Irrigate when balance is 3.5 cm

Date	(1) Days after transplanting or emergence	(2) Observed sunshine hours	(3) Estimated daily evapotranspiration (ET) cm/day	(4) Rainfall cm	(5) Net irrigation application cm	(6) Daily balance cm	(7) Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
			Balance Brought Forward 5.74				
1	8	8	0.13			5.61	
2	9	0	.13	1.37		6.10	FC
3	10	4	.13			5.97	
4	11	11	.15			5.82	
5	12	11	.15			5.67	
6	13	11	.18			5.49	ET rate change
7	14	6	.15	1.02		6.10	FC
8	15	12	.18			5.92	
9	16	0	.15	2.29		6.10	1.3>FC.Allow 2 days
10	17	6	.15			6.10	Free water use
11	18	12	.18			6.10	Free water use
12	19	12	.23			5.87	Sprayed, cultivated
13	20	12	.23			5.64	
14	21	6	.20			5.44	
15	22	3	.18	0.41		5.26	Less than 0.5 rain
16	23	3	.18	.63		5.71	
17	24	4	.20			5.51	
18	25	6	.25			5.26	
19	26	3	.20	.61		5.67	
20	27	10	.25	.05		5.42	Less than 0.5 rain
21	28	12	.30			5.12	Field moisture check
22	29	13	.30			4.82	
23	30	10	.25			4.57	
24	31	8	.30	.13		4.27	Rain less than 0.5
25	32	12	.38			3.89	
26	33	6	.30	.13		3.59	Rain less than 0.5
27	34	5	.30	.81		4.10	
28	35	9	.30	.18		3.80	
29	36	12	.38			3.42	Laid sprinkler pipe
30	37	13	.43		2.79	5.78	
31							
Totals			6.84	7.63	2.79		

Table 15-4—Moisture balance for scheduling irrigation (continued)

Month May 19 79

Farm I. M. Manager

County Sussex

Field 2

Soil type Sassafras sl

Crop Early Potatoes Root depth 46 cm

Available Moisture Capacity 6.1 cm

Irrigate when balance is 3.5 cm

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Date	Days after transplanting or emergence	Observed sunshine hours	Estimated daily evapotranspiration (ET) cm/day	Rainfall cm	Net irrigation application cm	Daily balance cm	Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
			Balance Brought Forward 5.78				
1	38	13	0.43			5.35	Sprayed
2	39	12	.43			4.92	
3	40	10	.35			4.57	
4	41	10	.35			4.22	
5	42	12	.43			3.79	
6	43	10	.41			3.38	
7	44	13	.50		2.92	5.80	
8	45	12	.50			5.3	Sprayed
9	46	14	.50			4.8	
10	47	12	.50			4.3	
11	48	12	.50			3.8	
12	49	12	.50			3.3	
13	50	10	.43		3.05	5.92	
14	51	10	.43			5.49	
15	52	11	.50			4.99	
16	53	9	.43			4.56	
17	54	12	.50			4.06	
18	55	14	.50			3.56	
19	56	12	.50		3.05	6.11	
20	57	14	.50			5.61	Sprayed
21	58	10	.43			5.18	Field moisture check
22	59	14	.50			4.68	
23	60	12	.50			4.18	
24	61	12	.48		2.92	6.10	FC
25	62	10	.41			5.69	
26	63	10	.41			5.28	Sprayed
27	64	8	.41			4.87	
28	65	4	.41	0.43		4.46	
29	66	0	.33	1.73		5.86	
30	67	0	.30			5.56	
31	68	3	.30			5.26	
Totals			13.67	2.16	11.94		

Table 15-4—Moisture balance for scheduling irrigation (continued)

Month June 19 79

Farm I. M. Manager

County Sussex

Field 2

Soil type Sassafras sl

Crop Early Potatoes Root depth 46 cm

Available Moisture Capacity 6.1 cm

Irrigate when balance is 3.5 cm

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Date	Days after transplanting or emergence	Observed sunshine hours	Estimated daily evapotranspiration (ET) cm/day	Rainfall cm	Net irrigation application cm	Daily balance cm	Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
			Balance Brought Forward 5.26				
1	69	13	0.46			4.80	
2	70	10	0.38			4.42	
3	71	0	0.30	3.23		6.10	FC
4	72		0.38			6.10	
5	73		0.36			6.10	ET estimated
6	74		0.36			5.74	
7	75	13	0.43			5.31	
8	76	8	0.36	0.13		4.95	
9	77	8	0.36	0.20		4.59	
10	78	10	0.36			4.23	
11	79	12	0.38			3.85	
12	80	3	0.25	0.25		3.60	
13	81	12	0.38			3.22	
14	82	12	0.38			2.84	
15	83	3	0.20	0.25		2.64	Adjusted ET value
16	84	0	0.25	1.90		4.29	
17	85	2	0.23	0.36		4.06	
18	86	10	0.30			3.76	
19	87	6	0.30	0.84		4.30	
20	88	12					Killed tops
21	89						
22	90						
23	91						
24	92			0.02			
25	93			0.25			
26	94						
27	95						
28							
29							
30							Start digging
31							
Totals				7.43			

Table 15-4A—Moisture balance for scheduling irrigation

Month March 19 79

Soil type Sassafras sl

Farm I. M. Manager

Crop Early Potatoes Root depth 18 in

County Sussex

Available Moisture Capacity 2.40 in

Field 2

Irrigate when balance is 1.40 in

Date	(1) Days after transplanting or emergence	(2) Observed sunshine hours	(3) Estimated daily evapotranspiration (ET) in/day	(4) Rainfall in	(5) Net irrigation application in	(6) Daily balance in	(7) Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
			Balance Brought Forward			Note: Use ET Table for 90-day growing season.	
1							
2							
3							
4							
5				1.26		2.40	Field capacity (FC)
6							
7							
8							
9							
10							
11							
12							Planting date
13							
14							
15							
16		11				1.90	Estimated
17		2	0	0.31		2.21	
18		1	0	0.75		2.40	Total 2.96. 0.5>2.40
19		10	0.03			2.40	
20		6	0	0.36		2.40	
21		11	.03			2.37	Evaporation.surface
22		12	.03			2.34	Evaporation.surface
23		12	.03			2.31	Evaporation.surface
24		12	.03			2.28	Plant emergence
25	1	10	.04	0.08		2.24	Less than 0.2 rain
26	2	2	.04	0.78		2.40	0.5 over FC
27	3	10	.04			2.40	Free water use
28	4	3	.04	0.28		2.40	Free water use
29	5	10	.04			2.36	
30	6	11	.05			2.31	Sprayed
31	7	10	.05			2.26	ET rate change
Totals			.45	3.82			

Table 15-4A—Moisture balance for scheduling irrigation (continued)

Month April 19 79

Soil type Sassafras sl

Farm I. M. Manager

Crop Early Potatoes Root depth 18 in

County Sussex

Available Moisture Capacity 2.40 in

Field 2

Irrigate when balance is 1.40 in

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Date	Days after transplanting or emergence	Observed sunshine hours	Estimated daily evapotranspiration (ET) in/day	Rainfall in	Net irrigation application in	Daily balance in	Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
			Balance Brought Forward 2.26				
1	8	8	0.05			2.21	
2	9	0	.05	0.54		2.40	FC
3	10	4	.05			2.35	
4	11	11	.06			2.29	
5	12	11	.06			2.23	
6	13	11	.07			2.16	ET rate change
7	14	6	.06	0.40		2.40	FC
8	15	12	.07			2.33	
9	16	0	.06	0.90		2.40	0.5>FC.Allow 2 days
10	17	6	.06			2.40	Free water use
11	18	12	.07			2.40	Free water use
12	19	12	.09			2.31	Sprayed,cultivated
13	20	12	.09			2.22	
14	21	6	.08			2.14	
15	22	3	.07	0.16		2.07	Less than 0.2 rain
16	23	3	.07	0.25		2.25	
17	24	4	.08			2.17	
18	25	6	.10			2.07	
19	26	3	.08	0.24		2.23	
20	27	10	.10	0.02		2.13	Less than 0.2 rain
21	28	12	.12			2.11	Field moisture check
22	29	13	.12			1.99	
23	30	10	.10			1.89	
24	31	8	.12	0.05		1.77	Rain less than 0.2
25	32	12	.15			1.62	
26	33	6	.12	0.05		1.50	Rain less than 0.2
27	34	5	.12	0.32		1.70	Cultivate
28	35	9	.12	0.07		1.58	
29	36	12	.15			1.43	Laid sprinkler pipe
30	37	13	.17		1.1	2.40	
31							
Totals			2.71	3.00	1.15		

Table 15-4A—Moisture balance for scheduling irrigation (continued)

Month May 19 79

Farm I. M. Manager

County Sussex

Field 2

Soil type Sassafras sl

Crop Early Potatoes Root depth 18 in

Available Moisture Capacity 2.40 in

Irrigate when balance is 1.40 in

Date	(1) Days after transplanting or emergence	(2) Observed sunshine hours	(3) Estimated daily evapotranspiration (ET) in/day	(4) Rainfall in	(5) Net irrigation application in	(6) Daily balance in	(7) Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
			Balance Brought Forward		2.40		
1	38	13	0.17			2.23	Sprayed
2	39	12	.17			2.06	
3	40	10	.14			1.92	
4	41	10	.14			1.78	
5	42	12	.17			1.61	
6	43	10	.16			1.45	
7	44	13	.20		1.15	2.40	
8	45	12	.20			2.20	Sprayed
9	46	14	.20			2.00	
10	47	12	.20			1.80	
11	48	12	.20			1.60	
12	49	12	.20			1.40	
13	50	10	.17		1.20	2.40	
14	51	10	.17			2.23	
15	52	11	.20			2.03	
16	53	9	.17			1.86	
17	54	12	.20			1.66	
18	55	14	.20			1.46	
19	56	12	.20		1.20	2.40	
20	57	14	.20			2.20	Sprayed
21	58	10	.17			1.85	Field moisture check
22	59	14	.20			1.65	
23	60	12	.20			1.45	
24	61	12	.19		1.15	2.40	
25	62	10	.16			2.24	
26	63	10	.16			2.08	Sprayed
27	64	8	.16			1.92	
28	65	4	.16	0.13		1.76	
29	66	0	.13	0.68		2.31	
30	67	0	.12			2.19	
31	68	3	.12			2.07	
Totals			5.43	0.81	4.70		

Table 15-4A—Moisture balance for scheduling irrigation (continued)

Month June 19 79

Soil type Sassafras sl

Farm I. M. Manager

Crop Early Potatoes Root depth 18 in

County Sussex

Available Moisture Capacity 2.40 in

Field 2

Irrigate when balance is 1.40 in

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Date	Days after transplanting or emergence	Observed sunshine hours	Estimated daily evapotranspiration (ET) in/day	Rainfall in	Net irrigation application in	Daily balance in	Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
			Balance Brought Forward 2.07				
1	69	13	0.18			1.89	
2	70	10	.15			1.74	
3	71	0	.12	1.27		2.40	
4	72		.15			2.40	
5	73		.14			2.40	ET estimated
6	74		.14			2.26	
7	75	13	.17			2.09	
8	76	8	.14	0.05		1.95	
9	77	8	.14	0.08		1.81	
10	78	10	.14			1.67	
11	79	12	.15			1.52	
12	80	3	.10	0.10		1.42	
13	81	12	.15			1.27	
14	82	12	.15			1.12	
15	83	3	.08	0.10		1.04	Adjusted ET value
16	84	0	.10	0.75		1.69	
17	85	2	.09	0.14		1.60	
18	86	10	.12			1.48	
19	87	6	.12	0.33		1.69	
20	88	12					Killed tops
21	89						
22	90						
23	91						
24	92			0.01			
25	93			0.10			
26	94						
27	95						
28							
29							
30							Started digging
31							
Totals				2.93			

Table 15-5.—Sample—Estimated values of daily evapotranspiration for observed sunshine and crop stage of growth
[For potatoes during a 90-day growing season]

Days after transplanting or emergence	Observed weather and hours of sunshine					
	Cloudy 0-3		Fair 4-10		Bright 11-15	
	cm/day	in/day	cm/day	in/day	cm/day	in/day
0-6	0.10	0.04	[1]0.10	0.04	0.13	0.05
7-12	0.13	0.05	0.13	0.05	0.15	0.06
13-18	0.15	0.06	0.15	0.06	0.18	0.07
19-24	0.18	0.07	0.21	0.08	0.23	0.09
25-30	0.21	0.08	0.25	0.10	0.30	0.12
31-36	0.25	0.10	0.30	0.12	0.38	0.15
37-42	0.28	0.11	0.35	0.14	0.43	0.17
43-48	0.33	0.13	0.40	0.16	0.50	0.20
49-60	0.33	0.13	0.43	0.17	0.50	0.20
61-66	0.33	0.13	0.40	0.16	0.48	0.19
67-72	0.30	0.12	0.38	0.15	0.45	0.18
73-78	0.28	0.11	0.35	0.14	0.43	0.17
79-84	0.25	0.10	0.30	0.12	0.38	0.15
85-90	0.23	0.09	0.30	0.12	0.35	0.14

[1]In case it is impossible to observe weather conditions over a period of 1 or 2 days, use the underlined values for that period to bring the daily moisture balance up to date.

3. Should the recordkeeper be away for a day or two, select average values for consumptive use and record them in column 3.

4. Record the amount of rainfall in column 4. Amounts should be recorded to the nearest 0.01 cm (0.01 in).

5. From the preceding day's balance in column 6, subtract the ET use value in column 3. If rainfall exceeds 0.5 cm (0.2 in), column 4, add this value to the daily moisture balance to obtain the new daily balance. If the total exceeds the value for available moisture at field capacity in the root zone, enter in column 6 the available moisture, which has been determined and recorded in the heading of the form. If the total exceeds the available moisture value at field capacity by 1.3 cm (0.5 in) or more, continue the full moisture balance value for 2 succeeding days as shown in the example (tables 15-4 and 4A). During this 2-day period, the plants will be using the free water in the root zone.

6. Continue the daily accounting process until the balance recorded in column 6 approaches the value preselected for irrigation to begin. The daily balance shows the amount of remaining available moisture and indicates the amount of irrigation to be scheduled. The net irrigation to be applied is the difference between the current daily balance prior to the start of irrigation and available moisture-holding capacity plus the estimated evapotranspiration for that day. The gross application is the required net application divided by the expected application efficiency (expressed as a decimal). Add the net irrigation amount to the daily moisture balance to obtain the new daily balance. If some effective rainfall occurs during the irrigation, add this to the irrigation applied. As stated in item 5, irrigation plus rainfall should bring the soil to field capacity, but the balance cannot exceed the moisture-holding capacity of the soil.

Follow these six steps at the end of each day during the growing season until the crop has reached the desired maturity.

Adjustment Factors

If the daily moisture balance is allowed to drop below 50 percent of the total available moisture value, plants have increasing difficulty obtaining the moisture they need for vigorous growth. In such cases, daily evapotranspiration will be reduced.

If the crop was not irrigated when the daily moisture balance reached the 50-percent level, ET values from table 15-5 must be reduced. The actual reduction in ET rates varies with the kind of crop. However, the following factors can be used as a guide for estimating probable daily ET rates. For lowered moisture levels, multiply the value obtained from table 15-5 by the applicable factor for the existing moisture level.

Moisture level percent	Factor
40-50	0.8
30-40	0.6
20-30	0.2

Irrigation Procedure

If several days are required to irrigate the crop, the application for each succeeding day should be increased by the day's consumptive use. If more than 3 days are required to complete the irrigation, the following method may be used to adjust the application requirements:

1. Divide the number of days required to complete the irrigation into 2- or 3-day intervals.

2. Add 0.75 cm (0.3 in) or 1.3 cm (0.5 in), respectively, to the net application amount used for the previous interval.

Variations of this procedure may be used to fit individual situations.

Direct Gas Pressure Method for Scheduling Irrigation

Some operators regard keeping a daily moisture accounting record as burdensome. G. W. Eley and H. M. Kautz developed an equally or more accurate method that requires only occasional soil moisture checks. The irrigator can refer to the Soil Characteristics Sheet (table 15-6) for the particular area of the field to obtain the percentages of available moisture remaining and the centimeters (inches) of water needed in the effective root zone depth of the crop.

The equipment consists of a soil volume sampler, a sample drier, and a supply of Field Moisture Check Forms and Soil Characteristics Sheets. The Eley volumeter and a carbide moisture tester are used in this procedure. A tube sampler with an extension handle is convenient for sampling soils for moisture content after bulk densities have been determined.

This simplified method of irrigation water management eliminates daily recordkeeping and the need for estimating the effect of climatic factors and the stage of crop growth on daily consumptive use. It requires no accounting for soil moisture changes caused by rainfall or irrigation.

Once the Soil Characteristics Sheets have been developed for specific areas in the field, the irrigator needs to make carbide moisture tests of samples from appropriate depths in the field and refer the gage readings to the Soil Characteristics Sheets. The net centimeters (inches) of water to be applied to an area are the sum of the values for the soil layers sampled in the effective root zone depth.

It is necessary to have a Soil Characteristics Sheet for each typical soil or control area in the field. One Soil Characteristics Sheet will apply to all crops in the same area by using the appropriate effective root zone depths.

The irrigator should be given technical assistance to develop at least the first Soil Characteristics Sheet. In the interest of providing training and reducing the number of samples to be taken, it would be desirable for the technician to assist in developing the Soil Characteristics Sheets and to include the root zone depths for all crops to be grown in a particular field or fields.

Sample Problem

The following example outlines the procedure for preparing the Soil Characteristics Sheet. (See table 15-6.)

Table 15-6.

Soil Characteristics Sheet for Irrigation Water Management

Field: 3 **Crop:** potatoes

Farm: Sample **Location:** Upper end

Available Moisture Level[1] (Applies to all layers) (percent)	0 to 20-cm Soil Layer (0- to 8-in.)				20- to 38-cm Soil Layer (8- to 15-in.)				38- to 45-cm Soil Layer (15- to 18-in.)			
	Field Capacity[2] 18.9%	Wilting Point[3] 3.8%	Bulk Density[4] 1.56 g/cm³		Field Capacity 17.1%	Wilting Point 3.4%	Bulk Density 1.50 g/cm³		Field Capacity 18.2%	Wilting Point 4.6%	Bulk Density 1.45 g/cm³	
	Dry Weight Moisture (Percent)	Speedy Tester Gage Reading[5]	Net Water to Apply[6] (cm)	(in.)	Dry Weight Moisture (Percent)	Speedy Tester Gage Reading	Net Water to Apply (cm)	(in.)	Dry Weight Moisture (percent)	Speedy Tester Gage Reading	Net Water to Apply (cm)	(in.)
100 (F.C.)	18.9	16.4			17.1	15.1			18.2	15.9		
90	17.4	15.3	0.48	0.19	15.7	14.1	0.36	0.14	16.8	14.9	0.15	0.06
80	15.9	14.2	0.96	0.38	14.4	13.1	0.71	0.28	15.5	13.9	0.30	0.12
70[7]	14.4	13.1	1.45	0.57	13.0	12.0	0.67	0.42	14.1	12.8	0.46	0.18
60[7]	12.9	11.9	1.93	0.76	11.6	10.8	1.42	0.56	12.8	11.8	0.61	0.24
50[7]	11.3	10.6	2.41	0.95	10.3	9.7	1.78	0.70	11.4	10.7	0.76	0.30
40	9.8	9.3	2.90	1.14	8.9	8.5	2.13	0.84	10.0	9.5	0.91	0.36
30	8.3	7.9	3.38	1.33	7.5	7.2	2.49	0.98	8.7	8.3	1.07	0.42
20	6.8	6.5	3.86	1.52	6.1	5.9	2.84	1.12	7.3	7.0	1.22	0.48
10	5.3	5.2	4.34	1.71	4.8	4.8	3.20	1.26	6.0	5.3	1.37	0.54
0 (W.P.)	3.8	3.8	4.83	1.90	3.4	3.4	3.56	1.40	4.6	4.6	1.52	0.60

[1] The ratio of the centimeters (inches) of remaining available moisture to the field capacity in a specific soil layer, expressed as a percent. (One hundred (100) percent equals Field Capacity; zero (0) percent equals Permanent Wilting Point.)

[2] A field measurement of the amount of water retained in a well-drained soil, 1 to 4 days after a thorough wetting by rainfall or irrigation, expressed as a percent of the dry weight of the soil.

[3] The moisture content, expressed as a percent of the dry weight of the soil, at which plants can no longer extract moisture.

[4] The ratio of dry weight of the sample in grams to its volume in cubic centimeters.

[5] The moisture content of a specific soil sample, expressed as a percent of the wet weight of the soil.

[6] Net centimeters (inches) of water to bring the soil layer to field capacity. When different soil layers are utilized by a crop, the total net application is the sum of the net amounts required for each soil layer.

[7] Desirable time to start irrigation, depending on the crop and number of days required to irrigate the crop.

Given:

Soil–Sassafras sandy loam

0-20 cm (0-8 in) Dark-brown sandy loam; weak, fine granular structure; very friable.

20-38 cm (8-15 in) Yellowish-brown sandy loam; structureless to weak, medium subangular blocky structure; friable.

38-60 cm (15-24 in) Yellowish-brown sandy loam; weak, fine to medium subangular blocky structure; some very fine roots; some wormholes, and wormcasts.

Irrigated crops: peas, peppers, potatoes, snap-beans

Effective root depth: 30 to 45 cm (12 to 18 in)

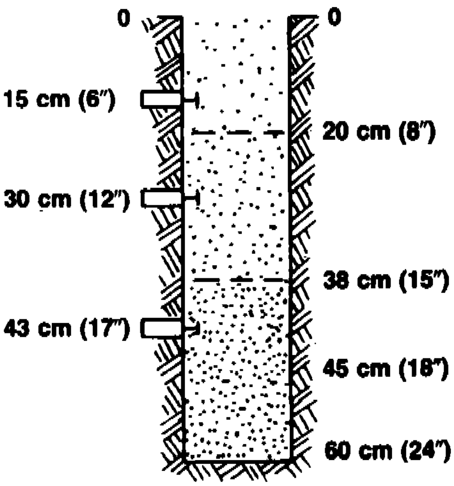
Moisture Percentage at Field Capacity

Determine the percentage of moisture at field capacity in each soil layer, using a carbide moisture tester and Eley volumeter.

1. Dig a hole slightly beyond the effective root depths to be considered.
2. Record in the heading of the Soil Characteristics Sheet the range in depth of the different soil layers and include effective root zone depths of crops to be irrigated. Use additional sheets if necessary.
3. Take test samples of the different textural layers as shown in figure 15-6.
4. Weigh a 26-g (0.92-oz) sample from the test sample taken from each layer with the volumeter. Record the volume of soil required to equal 26 g (0.92 oz). Determine the moisture percentage in each weighed sample by using the carbide moisture tester. The gage reading is the moisture percentage based on wet weight of the sample.
5. Record the gage reading for each soil layer on the line of the Soil Characteristics Sheet opposite 100 (F.C.). Convert these values to percentage of moisture based on dry weight of the sample by using the carbide moisture tester conversion chart (exhibit 15-6).

Figure 15-6

Sampling of Textural Layers



For example:

Soil layer (cm)	Soil layer (in)	Moisture tester gage reading	Percent moisture, dry weight of sample
0-20	0-8	16.4	18.9
20-38	8-15	15.1	17.1
38-60	15-24	15.9	18.2

6. Record the dry weight moisture percentage for each soil layer on the line of the Soil Characteristics Sheet, table 15-6, opposite 100 (F.C.).

Bulk Density Measurement

Compute the bulk density of the soil in each layer, using the formula:

$$\text{Bulk Density} = \frac{\text{Weight of Sample}}{\text{Volume of Sample}\left(1 + \frac{\text{Percent Moisture, Dry Weight}}{100}\right)}$$

Where:
Weight of samples equals 26 g (0.92 oz).
Volumes of samples equals 14.0, 14.8, and 15.2 cm^3 (0.85, 0.90, and 0.93 in^3), respectively. (Obtained while getting moisture percentage at field capacity.) Percent moisture, dry weight, equals 18.9, 17.1, and 18.2, respetively.

0- to 20-cm (0- to 8-in) layer:

$$\text{Bulk Density} = \frac{26}{(14.0)\left(1 + \frac{18.9}{100}\right)} = \frac{26}{14.0(1.189)} =$$

1.56 g/cm^3

20- to 38-cm (8- to 15-in) layer:

$$\text{Bulk Density} = \frac{26}{(14.8)\left(1 + \frac{17.1}{100}\right)} = \frac{26}{14.8(1.171)} =$$

1.50 g/cm^3

38- to 60-cm (15- to 24-in) layer:

$$\text{Bulk Density} = \frac{26}{(15.2)\left(1 + \frac{18.2}{100}\right)} = \frac{26}{15.2(1.182)} =$$

1.45 g/cm³

Record these values for the different layers in the spaces for bulk density in the heading of the Soil Characteristics Sheet.

Moisture Percentage at Wilting Point

From laboratory or other dependable data, obtain the moisture percentage at 15 atmospheres of soil moisture tension for the type of soil to be irrigated. If this information is not available, use the following fractions to estimate the moisture percentage at wilting point for each soil layer (not applicable to saline soils).

1. For loamy fine sand, use one-sixth of the field capacity percentage.
2. For very fine sandy loam, use one-fifth of the field capacity percentage.
3. For fine sandy loam, use one-fourth of the field capacity percentage.
4. For sand, sandy loam, loamy sand, loam, and silt loam, use one-third of the field capacity percentage.
5. For silty clay and clay, use one-half of the field capacity percentage.

Record these values in the spaces for wilting point in the heading of the Soil Characteristics Sheet.

Centimeters (Inches) of Available Moisture

Compute the centimeters (inches) of available moisture for each soil layer to the effective root depth selected. Use the values recorded in the upper part of the Soil Characteristics Sheet for each soil layer.

Available Moisture=

$$\frac{\text{Field Capacity} - \text{Wilting Percentage} \times \text{Bulk Density} \times \text{Depth of Soil Layer}}{100 \times 1}$$

0- to 20-cm layer:

$$\text{Available Moisture} = \frac{(18.9 - 3.8)(1.56)(20)}{100 \times 1}\ 4.71\text{ cm, use }4.70\text{ cm}$$

0- to 8-in layer:

$$\text{Available Moisture} = \frac{(18.9 - 3.8)(1.56)(8)}{100 \times 1} = 1.89\text{ in, use }1.90\text{ in}$$

20- to 38-cm layer:

$$\text{Available Moisture} = \frac{(17.1 - 3.4)(1.50)(18)}{100 \times 1} = 3.69\text{ cm, use }3.70\text{ cm}$$

8- to 15-in layer:

$$\text{Available Moisture} = \frac{(17.1 - 3.4)(1.50)(7)}{100 \times 1} = 1.44\text{ in, use }1.40\text{ in}$$

38- to 45-cm layer[1]:

$$\text{Available Moisture} = \frac{(18.2 - 4.6)(1.45)(7)}{100 \times 1} = 1.38\text{ cm, use }1.40\text{ cm}$$

15- to 18- in layer:

$$\text{Available Moisture} = \frac{(18.2 - 4.6)(1.45)(3)}{100 \times 1} = 0.59\text{ in, use }0.60\text{ in}$$

Total Available Moisture to 45-cm (18-in) root depth = 9.8 cm (3.9 in)

Net Moisture Requirement at Each Moisture Level

Beginning with the "available moisture level" of zero at the bottom of the "Equivalent Moisture Table" (exhibits 15-7 and 7A), follow horizontally until a number is found that is equal to the centimeters (inches) of available moisture at field capacity for the soil layer. Copy this column of figures onto the Soil Characteristics Sheet in the column headed "Net Water to Apply." Repeat for each soil layer.

Determining Adjustment Percentages

Calculate for each soil layer the adjustment percentage needed to relate percentage moisture

[1]*Note: The 38- to 60-cm (15- to 24-in) soil layer is 23 cm (9 in) thick, but in this example the crop roots effectively use only 7 cm (3 in) of this layer.*

dry weight to the available moisture percentage. The adjustment percentage is determined for the range of available moisture levels from 100 percent (field capacity) to zero (permanent wilting point).

$$\text{Adjustment Percentage} = \frac{\text{Field Capacity Percentage} - \text{Wilting Point Percentage}}{10}$$

Use percentage values at field capacity and wilting point which have been found and recorded on the Soil Characteristics Sheet.

0- to 20-cm (0- to 8-in) layer:

$$\text{Adjustment Percentage} = \frac{18.9 - 3.8}{10} = \frac{15.1}{10} = 1.51$$

20- to 38-cm (8- to 15-in) layer:

$$\text{Adjustment Percentage} = \frac{17.1 - 3.4}{10} = \frac{13.7}{10} = 1.37$$

38- to 45-cm (15- to 18-in) layer:

$$\text{Adjustment Percentage} = \frac{18.2 - 4.6}{10} = \frac{13.6}{10} = 1.36$$

Dry Weight Moisture Percentages at Each Moisture Level

Insert the field capacity percentage for each soil layer in the "Dry Weight Moisture Percentage" column of the Soil Characteristics Sheet opposite the 100-percent figure in the column "available moisture level."

From the field capacity percentage for each soil layer, subtract the applicable adjustment percentage to obtain the relative dry weight moisture percentage for the 90-percent available moisture level. Repeat this procedure until the available moisture level of zero is reached.

For example:

0- to 20-cm (0- to 8-in) layer:

100 percent= Field Capacity= 18.90 percent dry weight, record 18.9

90 percent= 18.90 − 1.51 = 17.39 percent dry weight, record 17.4

80 percent= 17.39 − 1.51 = 15.88 percent dry weight, record 15.9

Complete the other columns for other soil layers similarly.

Gage Readings for Each Dry Weight Moisture Percentage

Locate in the body of the carbide moisture tester conversion chart (exhibit 15-6) the correct dry weight percentage for each level of moisture and find its corresponding gage reading. Record this value for each level of soil moisture in the "Moisture Tester Gage Reading" column on the Soil Characteristics Sheet.

This completes the development of the Soil Characteristics Sheet for crops to a 45-cm (18-in) root zone depth. The information can be applied now for field use.

Checking and Recording Soil Moisture

With the Soil Characteristics Sheet prepared, the irrigator needs only to check the soil moisture to determine when and how much water to apply. As the need for irrigation approaches, as indicated by soil moisture estimates, the irrigator simply makes a moisture check with the carbide moisture tester at the typical field locations. For many soils, a tube sampler similar to the Oakfield Probe is useful for this check.

Assume that the crop is potatoes with a 45-cm (18-in) root depth. The field information obtained is recorded in the first four columns of the Field Moisture Check Sheet, as shown on table 15-7. Included are the date of sampling, the soil layers sampled, the depths at which the samples were taken, and the carbide moisture tester gage reading for each sample.

Use of the Soil Characteristics Sheet

The irrigator uses the Soil Characteristics Sheet to find the gage reading for each soil layer that corresponds to the gage readings that were recorded in column 4 of the Field Moisture Check Sheet. Reading horizontally and to the left on the

Soil Characteristics Sheet, the irrigator will find the comparable available moisture level and record this information in column 5 of the Field Moisture Check Sheet. Then reading horizontally to the right the irrigator will find the comparable net water to apply and record it in column 6. Some simple interpolations may be necessary if the gage readings obtained in the field do not correspond exactly to those shown on the Soil Characteristics Sheet. See the example shown in table 15-6 and the interpolated values in column 6 of the Field Moisture Check Sheet.

Again referring to the Field Moisture Check Sheet, the sum of the figures in column 6 for each sampling location represents the net centimeters (inches) of water to apply to bring the effective root zone depth up to field capacity. The percentages of available moisture level recorded in column 5 will indicate whether the crop needs irrigation.

If the crop does not need irrigating at this time, the irrigator can repeat the moisture check in 2 or 3 days and record the date and information on the Field Moisture Check Sheet. By noting the amount that the available moisture level has declined since the earlier moisture check, the irrigator can closely approximate when another check should be made or can start irrigating.

If the crop had a 30-cm (12-in) root zone depth, moisture check samples would normally be taken at depths of about 12 and 25 cm (5 and 10 in). The required net irrigation needed at the time of sampling would be the sum of the net water needed in the 0- to 20-cm (0- to 8-in) layer plus a proportional amount of the value indicated for the 20- to 38-cm (8- to 15-in) layer.

For example:

Soil layer			Net water to apply	
cm	in		cm	in
0-20	0-8		2.5	1.0
20-30	8-12		0.7	$\frac{4}{7}(0.5)=0.3$
		Total	3.2	1.3

Table 15-7

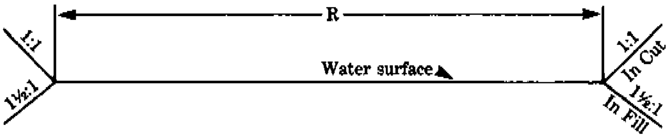
Field Moisture Check Sheet for Determining When to Irrigate and How Much Water to Apply

(1) Date	(2) Soil Layer	(3) Sample Depth	(4) Gage Reading	(5) Available Moisture Level	(6) Net Water to Apply	Notes
(Month & day)	(cm)	(cm)	(percent)	(percent)	(cm)	
June 11	0-20	15	10.6	50	2.5	45 cm depth
	20-38	30	11.4	65	1.25	for potatoes
	38-45	40	14.4	85	0.23	Upper end
					3.98	Field 3
(Month & day)	(inches)	(inches)	(percent)	(percent)	(inches)	
June 11	0-8	6	10.6	50	1.0	18" depth for
	8-15	12	11.4	65	0.5	potatoes
	15-18	16	14.4	85	0.1	Upper end
					1.6	Field 3

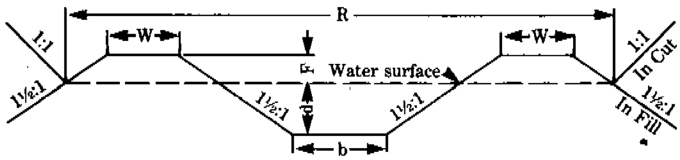
EXHIBITS

Exhibit 15-1

Irrigation Ditch Sections with Required Lateral Beds



Lateral Bed Before Ditch is Pulled



Finished Ditch Section

								s = 0.0005				s = 0.001				s = 0.002				s = 0.003			
								n = 0.03		n = 0.04		n = 0.03		n = 0.04		n = 0.03		n = 0.04		n = 0.03		n = 0.04	
Ditch No.	b	d	F	W	R	A	R	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
	ft	ft	ft	ft	ft	ft²	ft	ft/s	ft³/s	ft/s	ft³/s	ft/s	ft³/s	ft/s	ft³/s	ft/s	ft³/s	ft/s	ft³/s	ft/s	ft³/s	ft/s	ft³/s
612	0.5	1.0	0.5	1.00	8.5	2.00	0.49	0.69	1.4	0.51	1.0	0.97	1.9	0.73	1.5	1.37	2.7	1.03	2.1	1.68	3.4	1.26	2.5
1212	1.0	1.0	0.5	1.50	10.0	2.50	0.54	0.73	1.8	0.55	1.4	1.03	2.6	0.78	2.0	1.47	3.7	1.10	2.8	1.79	4.5	1.35	3.4
1812	1.5	1.0	0.5	2.00	11.5	3.00	0.59	0.78	2.3	0.58	1.7	1.10	3.3	0.83	2.5	1.50	4.7	1.17	3.5	1.91	5.7	1.43	4.3
2412	2.0	1.0	0.5	2.50	13.0	3.50	0.62	0.81	2.8	0.60	2.1	1.13	4.0	0.86	3.0	1.61	5.6	1.21	4.2	1.97	6.9	1.48	5.2
1214	1.0	1.2	0.7	1.25	11.3	3.36	0.63	0.81	2.7	0.61	2.0	1.15	3.9	0.87	2.9	1.63	5.5	1.22	4.1	1.99	6.7	1.50	5.0
1814	1.5	1.2	0.7	1.50	12.3	3.96	0.68	0.86	3.4	0.64	2.5	1.21	4.8	0.91	3.6	1.71	6.8	1.28	5.1	2.09	8.3	1.57	6.2
2414	2.0	1.2	0.7	2.00	13.8	4.56	0.72	0.89	4.1	0.67	3.1	1.25	5.7	0.94	4.3	1.78	8.1	1.33	6.1	2.18	9.9	1.63	7.4
1816	1.5	1.33	0.77	1.75	13.6	4.65	0.74	0.90	4.2	0.68	3.2	1.28	6.0	0.96	4.5	1.81	8.4	1.36	6.3	2.22	10.4	1.06	7.7
2416	2.0	1.33	0.77	2.00	14.6	5.31	0.78	0.94	4.9	0.71	3.8	1.33	7.1	0.99	5.3	1.88	10.0	1.41	7.5	2.30	12.3	1.72	9.2
2418	2.0	1.5	1.0	1.50	15.5	6.38	0.86	1.00	6.4	0.75	4.8	1.42	9.1	1.06	6.8	2.00	12.8	1.50	9.6	2.45	15.6	1.83	11.7
3618	3.0	1.5	1.0	2.00	17.5	7.88	0.94	1.06	8.4	0.80	6.3	1.50	11.8	1.12	8.8	2.13	16.8	1.59	12.5	2.60	20.5	1.95	15.4
2421	2.0	1.75	1.1	1.75	17.4	8.10	0.98	1.09	8.8	0.82	6.6	1.55	12.6	1.15	9.3	2.19	17.7	1.64	13.3	2.67	21.6	2.00	16.2
3621	3.0	1.75	1.1	2.50	19.9	9.85	1.06	1.15	11.3	0.86	8.5	1.63	16.1	1.22	12.0	2.30	22.7	1.73	17.0	2.82	27.8	2.11	20.8
4821	4.0	1.75	1.1	3.00	21.9	11.60	1.13	1.20	13.9	0.90	10.4	1.70	19.7	1.27	14.7	2.40	27.8	1.80	20.9	2.94	34.1	2.21	25.6
3624	3.0	2.0	1.3	2.25	21.3	12.00	1.18	1.24	14.9	0.93	11.2	1.75	21.0	1.31	15.7	2.47	29.6	1.86	22.3	3.03	36.4	2.27	27.2
4824	4.0	2.0	1.3	3.00	23.8	14.00	1.25	1.28	17.9	0.96	13.4	1.82	25.5	1.36	19.0	2.57	36.0	1.93	27.0	3.15	44.1	2.36	33.0

A = Cross-sectional area in square feet.
R = Hydraulic radius in feet.
n = Coefficient of roughness.
Use n = 0.03 for bare ground.
Use n = 0.04 for grassed ditch bottom.

s = Slope in feet per foot
V = Velocity in feet per second
Q = Capacity of ditch in cubic feet per second.

Class	Irrigation slope 1/	Cross slope	Possible irrigation water efficiencies	Irrigation operation labor requirement	Method limitations	Leveling requirement
A_1	Uniform but not more than 0.05 percent	None	High	Very low	None	None
A_2	Uniform				Length of level borders is restricted.	
B_1		Uniform but not more than 0.3 percent			Length of level borders restricted. Border widths are restricted.	Leveling desirable to increase length or width of level borders.
B_2		Variable but not more than 0.3 percent		Low		Leveling desirable to reduce labor requirement.
B_3		Either uniform or variable and more than 0.3 percent but not more than 0.5 percent		Moderately low	Border widths are very restricted. Level borders not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils. Corrugations must have down-slope of at least four times cross slope.	
C_1	Fairly uniform - (When slopes are over 0.5 percent, convex slopes have maximum grades not over twice minimum; concave slopes have maximum grade not over 1 1/2 times minimum. Undulating slopes not permissible.)	Uniform or variable but not more than 0.3 percent	Good		Level borders not permissible. Border widths are restricted.	Leveling desirable to reduce labor requirement and improve irrigation efficiencies.
C_2		Uniform or variable but not more than 0.5 percent			Border widths are very restricted. Level borders not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils. Corrugations must have down-slope of at least four times cross slope.	
C_3	Either uniform or fairly uniform as defined above	Either uniform or variable and more than 0.5 percent		Moderate to high	Applicable only for contour ditches or to cross slope or contour furrow irrigation within special limitations of furrow depth and soil texture.	
D_1	Variable but without level reaches or reverse grades	Variable but not more than 0.3 percent	Poor	Moderate	Border widths are restricted. Level borders or corrugations not permissible.	Leveling required for conservation irrigation.
D_2		Variable but not more than 0.5 percent		High	Border widths are very restricted. Level borders or corrugations not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils.	
E		Variable and more than 0.5 percent	Very poor	Very high	Applicable only for contour ditches or furrows within special limitations of furrow depth and soil texture.	

1/ Maximum and minimum downfield grades are limited by (1) requirements for drainage, (2) protection from erosion by storm runoff, and (3) the criteria for the irrigation method to be used.

Exhibit 15-2—Relief classes for surface-irrigated land.

Exhibit 15-3

Discharge of Aluminum Siphon Tubes at Various Heads

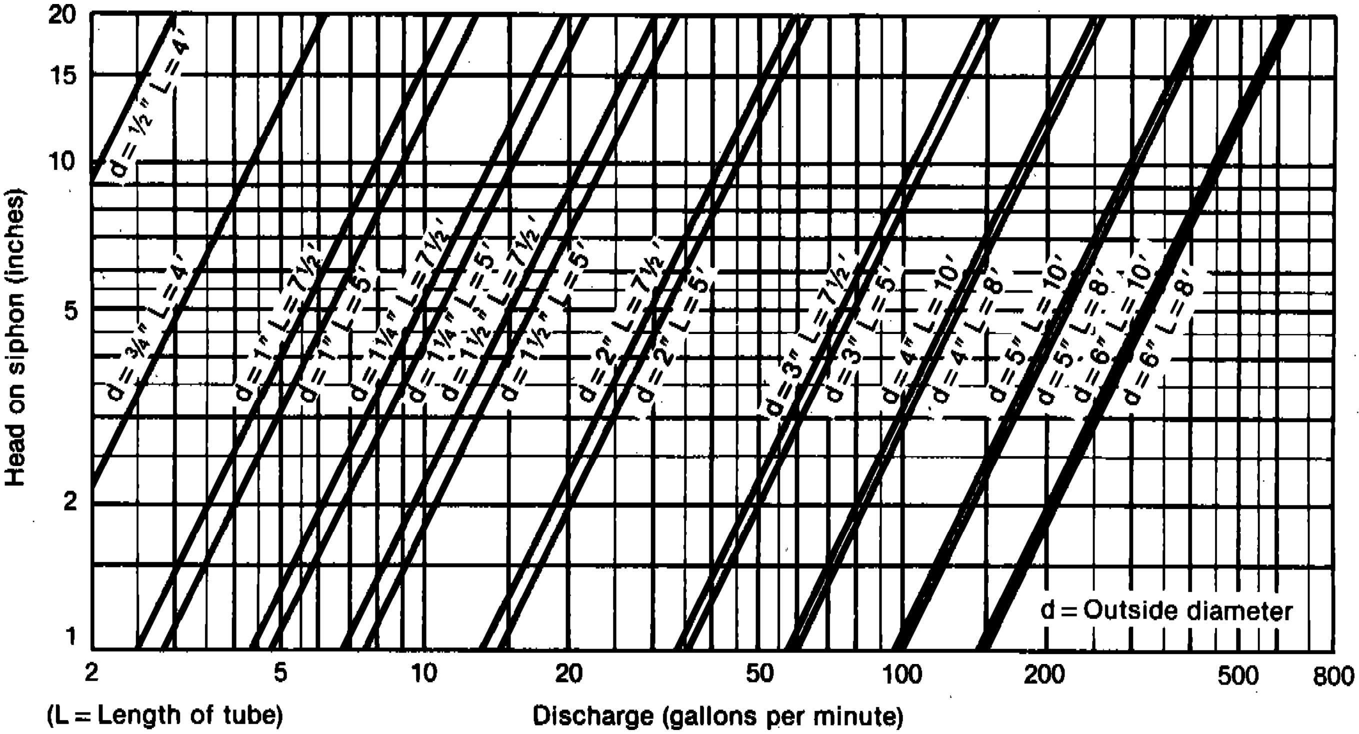


Exhibit 15-4

Multiple Outlet Factor for Gated Pipe

Number of Outlets	Multiple Outlet Factor
5	0.44
10	0.39
15	0.37
20	0.36
30	0.35
50	0.34
100	0.34
∞	0.33

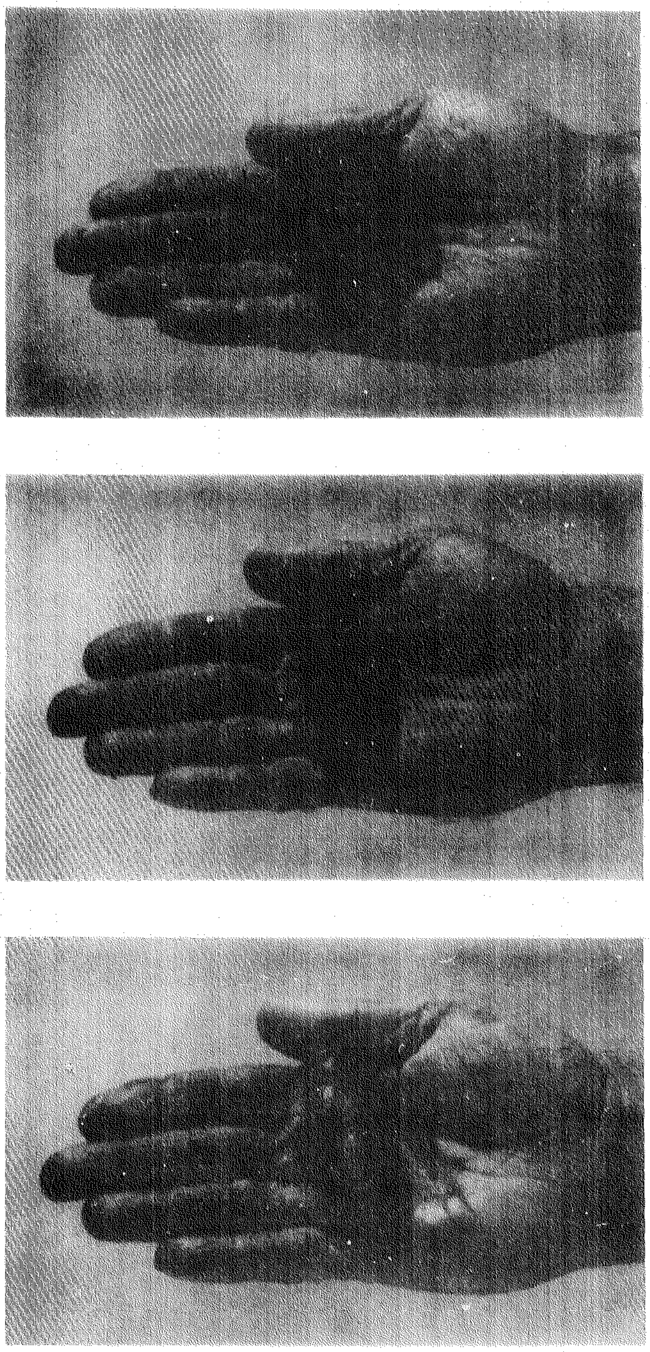


Exhibit 15-5(a) Moderately Fine Texture. *Top*: 0 to 33% available moisture—somewhat crumbly and slightly crusted. Will "ball" with pressure but breaks down easily. *Center*: 34 to 66% available moisture—forms a ball under pressure. Somewhat plastic and "slicks" slightly with pressure. Will "ribbon out" between thumb and forefinger. *Bottom:* 67 to 100% available moisture—"balls" readily. Is very pliable. "Ribbons out" easily. Has a slick feeling.

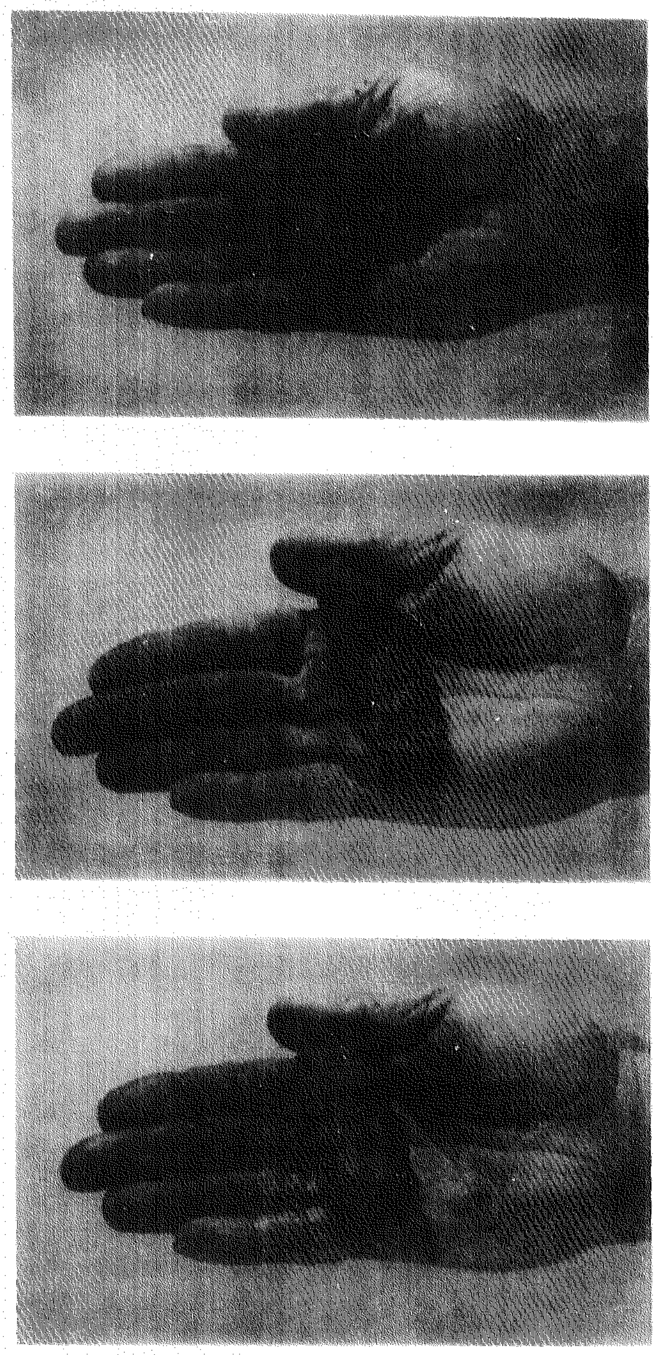
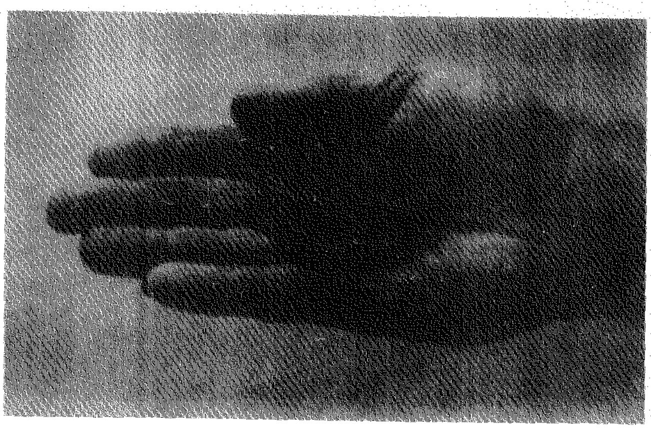
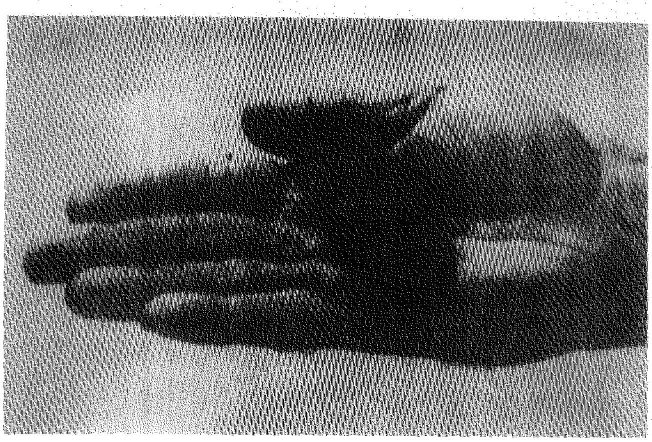


Exhibit 15-15(b) Medium Texture. *Top*: 0 to 33% available moisture—tends to hold together with hand pressure but crumbles easily. *Center:* 34 to 66% available moisture—forms a ball under pressure. Somewhat plastic. "Slicks" slightly with pressure. *Bottom:* 67 to 100% available moisture—forms a ball easily. Is very pliable. "Slicks" readily.





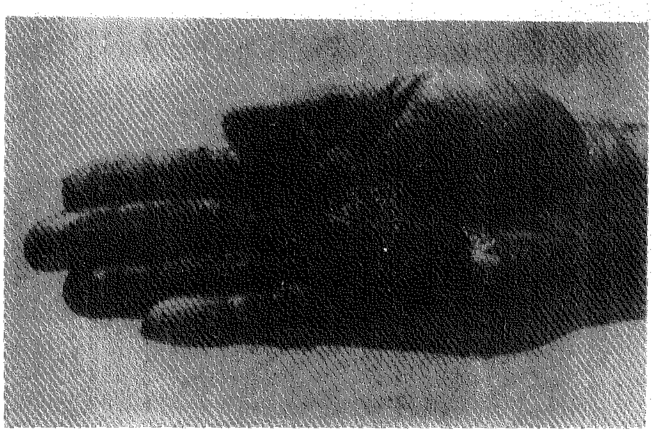


Exhibit 15-5(c) Coarse Texture. *Top:* 0 to 33% available moisture—dry, loose, and single grained. Flows through fingers. *Center*: 34 to 66% available moisture—appears to be dry. Does not form a ball under pressure. *Bottom*: 67 to 100% available moisture—sticks together slightly. Forms a weak ball. Breaks easily and will not "slick."

Exhibit 15-6

Carbide Moisture Tester Conversion Chart

Gage Reading[1]	Oven dry moisture (percent)									
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
2	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
3	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
4	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9
5	5.1	5.2	5.3	5.4	5.5	5.7	5.8	5.9	6.0	6.1
6	6.2	6.3	6.4	6.5	6.6	6.8	6.9	7.0	7.1	7.2
7	7.3	7.4	7.5	7.6	7.7	7.9	8.0	8.1	8.2	8.3
8	8.4	8.5	8.6	8.7	8.8	9.0	9.1	9.2	9.3	9.4
9	9.5	9.6	9.7	9.8	9.9	10.1	10.2	10.3	10.4	10.5
10	10.6	10.7	10.8	11.0	11.1	11.2	11.3	11.4	11.6	11.7
11	11.8	11.9	12.0	12.2	12.3	12.4	12.5	12.6	12.8	12.9
12	13.0	13.1	13.3	13.4	13.5	13.7	13.8	13.9	14.0	14.2
13	14.3	14.4	14.6	14.7	14.8	15.0	15.1	15.2	15.3	15.5
14	15.6	15.7	15.9	16.0	16.2	16.3	16.4	16.6	16.7	16.9
15	17.0	17.1	17.3	17.4	17.5	17.7	17.8	17.9	18.0	18.2
16	18.3	18.4	18.6	18.7	18.9	19.0	19.1	19.3	19.4	19.6
17	19.7	19.8	20.0	20.1	20.3	20.4	20.5	20.7	20.8	21.0
18	21.1	21.3	21.4	21.6	21.7	21.9	22.0	22.2	22.3	22.5
19	22.6	22.8	22.9	23.1	23.2	23.4	23.5	23.7	23.8	24.0
20	24.1	24.3	24.4	24.6	24.7	24.9	25.0	25.2	25.3	25.5
21	25.6	25.8	25.9	26.1	26.2	26.4	26.5	26.7	26.8	27.0
22	27.1	27.3	27.4	27.6	27.7	27.9	28.0	28.2	28.3	28.5
23	28.6	28.8	28.9	29.1	29.2	29.4	29.6	29.7	29.9	30.0
24	30.2	30.4	30.5	30.7	30.8	31.0	31.1	31.3	31.4	31.6
25	31.7	31.9	32.0	32.2	32.3	32.5	32.7	32.8	33.0	33.1
26	33.3	33.5	33.6	33.8	33.9	34.1	34.3	34.4	34.6	34.7
27	34.9	35.1	35.2	35.4	35.5	35.7	35.9	36.0	36.2	36.3
28	36.5	36.7	36.8	37.0	37.1	37.3	37.5	37.6	37.8	37.9
29	38.1	38.3	38.4	38.6	38.8	39.0	39.1	39.3	39.5	39.6
30	39.8	40.0	40.1	40.3	40.5	40.7	40.8	41.0	41.2	41.3
31	41.5	41.7	41.8	42.0	42.2	42.4	42.5	42.7	42.9	43.0
32	43.2	43.4	43.5	43.7	43.8	44.0	44.2	44.3	44.5	44.6
33	44.8	45.0	45.1	45.3	45.5	45.7	45.8	46.0	46.2	46.3

[1] Carbide moisture tester—3-minute readings.

Exhibit 15-7

Equivalent Moisture Table for Relating Available Moisture Level to Net Centimeters of Water to Apply

Available moisture level (Percent)	Net water to apply (cm)															
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0.05	0.08	0.10	0.13	0.15	0.18	0.20	0.23	0.25	0.28	0.30	0.33	0.35	0.38	0.40	0.43
80	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85
70	.15	.23	.30	.38	.45	.52	.60	.67	.75	.82	.90	.97	1.05	1.12	1.20	1.27
60	.20	.30	.40	.50	.60	.70	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70
50	.25	.38	.50	.63	.75	.88	1.00	1.13	1.25	1.38	1.50	1.63	1.75	1.78	2.00	2.13
40	.30	.45	.60	.75	.90	1.05	1.20	1.35	1.50	1.65	1.80	1.95	2.10	2.25	2.40	2.55
30	.35	.53	.70	.88	1.05	1.23	1.40	1.58	1.75	1.83	2.10	1.28	1.45	1.53	2.80	2.98
20	.40	.60	.80	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.40
10	.45	.68	.90	1.13	1.35	1.58	1.80	2.03	2.25	2.48	2.70	2.93	3.15	3.38	3.60	3.83
0	.50	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.15	4.00	4.26

100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0.45	0.48	0.50	0.53	0.55	0.58	0.60	0.63	0.65	0.68	0.70	0.73	0.75	0.78	0.80	0.83
80	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.30	1.35	1.40	1.50	1.55	1.60	1.65
70	1.35	1.43	1.50	1.58	1.65	1.73	1.80	1.88	1.95	2.03	2.10	2.18	2.25	2.33	2.40	2.48
60	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10	3.20	3.30
50	2.25	2.38	2.50	2.63	2.75	2.88	3.00	3.13	3.25	3.38	3.50	3.63	3.75	3.88	4.00	4.13
40	2.70	2.85	3.00	3.15	3.30	3.45	3.60	3.75	3.90	4.05	4.20	4.35	4.50	4.65	4.80	4.95
30	3.15	3.33	3.50	3.68	3.85	4.03	4.20	4.38	4.55	4.73	4.90	5.08	5.25	5.43	5.60	5.78
20	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00	5.20	5.40	5.60	5.80	6.00	6.20	6.40	6.60
10	4.05	4.28	4.50	4.73	4.95	5.17	5.40	5.62	5.85	6.08	6.30	6.53	6.75	6.98	7.20	7.43
0	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25

100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0.85	0.88	0.90	0.93	0.95	0.98	1.00	1.03	1.05	1.08	1.10	1.13	1.15	1.18	1.20	1.25	1.25
80	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50
70	2.55	2.63	2.70	2.78	2.85	2.93	3.00	3.08	3.15	3.23	3.30	3.38	3.45	3.53	3.60	3.68	3.75
60	3.40	3.50	3.60	3.70	3.80	3.90	4.00	4.10	4.20	4.30	4.40	4.50	4.60	4.70	4.80	4.90	5.00
50	4.25	4.38	4.50	4.63	4.75	4.88	5.00	5.13	5.25	5.38	5.50	5.63	5.75	5.88	6.00	6.13	6.25
40	5.10	5.25	5.40	5.55	5.70	5.85	6.00	6.15	6.30	6.45	6.60	6.75	6.90	7.05	7.20	7.35	7.50
30	5.95	6.13	6.30	6.48	6.65	6.83	7.00	7.18	7.35	7.53	7.70	7.88	8.05	8.23	8.40	8.58	8.75
20	6.80	7.00	7.20	7.40	7.60	7.80	8.00	8.20	8.40	8.60	8.80	9.00	9.20	9.40	9.60	9.80	10.00
10	7.65	7.88	8.10	8.33	8.55	8.78	9.00	9.23	9.45	9.68	9.90	10.13	10.35	10.58	10.80	11.03	11.25
0	8.50	8.75	9.00	9.25	9.50	9.75	10.00	10.25	10.50	10.75	11.00	11.25	11.50	11.75	12.00	12.25	12.50

INSTRUCTIONS: Beginning at the Available Moisture Level of zero at the bottom of table, follow horizontally until a number is found that equals the centimeter of Available Moisture at field capacity for the soil layer. Copy this column of figures into the Soil Characteristics Sheet column headed "Net Water to Apply."

Exhibit 15-7A

Equivalent Moisture Table for Relating Available Moisture Level to Net Inches of Water to Apply

Available moisture level (Percent)	Net water to apply (in)															
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17
80	.04	.06	.08	.10	.12	.14	.16	.18	.20	.22	.24	.26	.28	.30	.32	.34
70	.06	.09	.12	.15	.18	.21	.24	.27	.30	.33	.36	.39	.42	.45	.48	.51
60	.08	.12	.16	.20	.24	.28	.32	.36	.40	.44	.48	.52	.56	.60	.64	.68
50	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85
40	.12	.18	.24	.30	.36	.42	.48	.54	.60	.66	.72	.78	.84	.90	.96	1.02
30	.14	.21	.28	.35	.42	.49	.56	.63	.70	.77	.84	.91	.98	1.05	1.12	1.19
20	.16	.24	.32	.40	.48	.56	.64	.72	.80	.88	.96	1.04	1.12	1.20	1.28	1.36
10	.18	.27	.36	.45	.54	.63	.72	.81	.90	.99	1.08	1.17	1.26	1.35	1.44	1.53
0	.20	.30	.40	.50	.60	.70	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70

100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33
80	.36	.38	.40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66
70	.54	.57	.60	.63	.66	.69	.72	.75	.78	.81	.84	.87	.90	.93	.96	.99
60	.72	.76	.80	.84	.88	.92	.96	1.00	1.04	1.08	1.12	1.16	1.20	1.24	1.28	1.32
50	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65
40	1.08	1.14	1.20	1.26	1.32	1.38	1.44	1.50	1.56	1.62	1.68	1.74	1.80	1.86	1.92	1.98
30	1.26	1.33	1.40	1.47	1.54	1.61	1.68	1.75	1.82	1.89	1.96	2.03	2.10	2.17	2.24	2.31
20	1.44	1.52	1.60	1.68	1.76	1.84	1.92	2.00	2.08	2.16	2.24	2.32	2.40	2.48	2.56	2.64
10	1.62	1.71	1.80	1.89	1.98	2.07	2.16	2.25	2.34	2.43	2.52	2.61	2.70	2.79	2.88	2.97
0	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10	3.20	3.30

100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50
80	.68	.70	.72	.74	.76	.78	.80	.82	.84	.86	.88	.90	.92	.94	.96	.98	1.00
70	1.02	1.05	1.08	1.11	1.14	1.17	1.20	1.23	1.26	1.29	1.32	1.35	1.38	1.41	1.44	1.47	1.50
60	1.36	1.40	1.44	1.48	1.52	1.56	1.60	1.64	1.68	1.72	1.76	1.80	1.84	1.88	1.92	1.96	2.00
50	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50
40	2.04	2.10	2.16	2.22	2.28	2.34	2.40	2.46	2.52	2.58	2.64	2.70	2.76	2.82	2.88	2.94	3.00
30	2.38	2.45	2.52	2.59	2.66	2.73	2.80	2.87	2.94	3.01	3.08	3.15	3.22	3.29	3.36	3.43	3.50
20	2.72	2.80	2.88	2.96	3.04	3.12	3.20	3.28	3.36	3.44	3.52	3.60	3.68	3.76	3.84	3.92	4.00
10	3.06	3.15	3.24	3.33	3.42	3.51	3.60	3.69	3.78	3.87	3.96	4.05	4.14	4.23	4.32	4.41	4.50
0	3.40	3.50	3.60	3.70	3.80	3.90	4.00	4.10	4.20	4.30	4.40	4.50	4.60	4.70	4.80	4.90	5.00

INSTRUCTIONS: Beginning at the Available Moisture Level of zero at bottom of table, follow horizontally until a number is found that equals the inches of Available Moisture at Field Capacity for the soil layer. Copy this column of figures into the Soil Characteristics Sheet column headed "Net Water to Apply."