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Chapter 6 Irrigation System Design

Contents:

Tables

Figures

Example

Exhibit

Chapter 6 Irrigation System Design

652.0600 General irrigation objective

Irrigation systems should have the capability to apply the amount of water needed by the crop in addition to precipitation. Irrigation applications should occur in a uniform and timely manner while minimizing losses and damage to soil, water, air, plant, and animal resources. Some irrigation systems also include water supply and delivery. Any irrigation system design requires adjustment in the field. Designs must be tailored to the skills and willingness of the irrigation decisionmaker to properly manage the system and make the adjustments.

To properly design and manage irrigation water, flow rates must be known. Therefore, water measurement is essential for farm and field delivery. Measurement of irrigation water is described in chapter 8 of this guide.

(a) System capacity requirements

The irrigation system must be able to deliver and apply the amount of water needed to meet the crop-water requirement. Along with meeting the seasonal water requirements, systems must supply enough water to prevent daily crop-water stress by satisfying the difference between evapotranspiration demands and available soil moisture supplied by rainfall or previous irrigations.

The irrigation decisionmaker must decide what water supply rate(s) will be used for designing system capacity. In arid and semiarid areas with high value crops, at least 90 to 95 percent probability of peak daily plant evapotranspiration may be required. With medium value crops, 80 percent may be adequate; and with low value crops, 50 percent may be sufficient.

If the soil can only store and provide water for a few days, meeting peak daily evapotranspiration rates may be desirable. With medium textured soils in semihumid and humid climatic areas, values less than peak daily rates may be sufficient, such as average daily rate for the peak month. Potential prolonged drought periods in any climatic area and high value crops may justify the higher cost of providing system capacity to meet peak daily crop use rates. National Engineering Handbook (NEH), Part 623 (Section 15), Chapter 2, Irrigation Water Requirements, provides a good description and examples for determining farm and project water requirements.

A system capacity greater than crop water use may be needed for other uses, such as frost protection. For example, where a sprinkler irrigation system is used for frost protection of orchards, large blocks must be continuously sprinkled during critical cold temperatures. This may require lower application rates than irrigation application would require, but larger areas are probably sprinkled at one time, thus requiring larger pumping plants and larger diameter distribution lines.

Typically as water costs increase, farm managers invest in better irrigation systems and management. They use techniques that have the potential to minimize water use by more uniform water application across the field and better control of the amount needed and applied by each irrigation. Changing or improving irrigation methods and systems may reduce total operating costs. However, even the most suitable irrigation system for a specific site can be mismanaged.

(b) Limiting factors

Limiting factors to adequately operate an irrigation system on a specific site include soils, crop, water, climatic conditions, and labor. See tables 5–3 through 5–7 in Chapter 5, Selection of Irrigation Systems, for negative, neutral, or positive factors affecting selection consideration. Other limitations to consider are:

Surface systems—High sediment laden irrigation water generally reduces intake rates, which on coarse textured soils may increase advance rates thereby improving distribution uniformity for the field. On medium and fine textured soils, a reduced intake rate may be undesirable.

Graded furrow systems—On furrow slopes greater than 1 percent and on highly erodible soils, erosion rates can be severe unless protective measures are provided.

Level basin and graded border systems—Larger heads of water are required to meet minimum flow depth requirements in a level basin or border (typically 5 to 7 cubic feet per second) and maintain reasonable field sizes. High uniformity can be attained with level basins on medium and low intake rate soils.

Low pressure continuous/self move center pivot and linear systems—Requires intense water, soil, and plant management for low intake soils, and at least a moderate amount of management on low to medium intake soils.

Micro—Water quality must be high except for basin bubbler systems, which use plastic tubing of 3/8 inch diameter and larger. Chemicals must be used to prevent algae growth in most systems.

(c) System design

An irrigation guide is valuable by giving general guidance for planning, design, layout, and operation of an irrigation system. Only application methods for which rational design methods exist are described. Wild flooding, border ditches, and nongraded furrows are not included. Presently, the only practical way to improve on the efficiency of these systems is by trial and error with adjustments being made during an irrigation.

Rational methods of design have their own limits. The data that goes into any irrigation system design includes two principal factors—soil intake rate and net application per irrigation. In some areas timing and availability of water can be a consideration for surface systems; additional principal factors are flow rate and erosion resistance. These factors are highly variable and can change with soil condition, from one field to another, for each crop stage of growth, from crop to crop, and from the first part of the season to the last part. The physical layout of a system can be installed according to data from the guide. Operational adjustments then must be made for differing field and crop conditions.

Design standards for irrigation practices are contained in the NRCS National Handbook of Conservation Practices, and Section IV of the Field Office Technical Guide.

652.0601 Surface irrigation

(a) General

The surface irrigation method is the application of irrigation water to the soil surface by gravity. Application systems vary. It is necessary to understand that a volume balance of water in a surface irrigation system must exist at all times. All water introduced at the head end of the system must be accounted for in surface flow or storage, infiltration, runoff, and a very small amount lost to evaporation during the time of irrigation. The amount lost to evaporation is generally neglected. In the overland flow process, an energy balance also exists. Flow or volume measurements can account for inflow, surface storage, and runoff. Infiltration volume can be measured by changes in soil-water content in the root zone before and after irrigation, with the remainder going to deep percolation below the plant root zone.

(1) Description and stages of typical surface water movement

Inflow—Irrigation stream flowing into a furrow, corrugation, rill, border, basin, or field.

Advance stage—Process of the leading edge of water moving across the field either in channel or as overland flow.

Advance rate—Time or rate at which the advance front moves across the field.

Storage stage—That portion of time or volume occurring between end of advance (or shutoff) and start of recession time, generally measured between specific points (and time) during an irrigation.

Recession stage (rate)—That portion of the irrigation time between inflow shutoff and beginning of recession at the upper end of the field. Recession rate is the rate at which the recession front moves over the surface. To be practical, recession ends when less than 10 percent of the wetted soil surface is covered by water.

Infiltration—A process or rate of water entering into the soil at the air-soil interface.

Outflow (runoff)—Volume depth or streamflow rate flowing past the end of the field.

Figure 6–1 displays the definitions and characteristics of surface irrigation. Table 6–1 displays gross irrigation application for a variety of net application depths and efficiencies.

This part of chapter 6 reflects existing methodology and calculation procedures and examples in NEH, part 623 (section 15), chapters 4 and 5. Reference to current academia and research involving what is described as the zero-inertia model will also be made.

Design procedures and examples provided in section 652.0605 are developed from state approved computer programs using existing methodology from chapters 4 and 5, or from Agricultural Research Service's publication, *Surface Irrigation Model, SRFR*. SRFR methodology will be used as the basis for future surface irrigation designs in NRCS. Trial applications of SRFR in some locations have shown the model more nearly fits actual field conditions than those from existing methodology given in NEH part 623, chapters 4 and 5.

Figure 6–1 Surface irrigation stage definitions

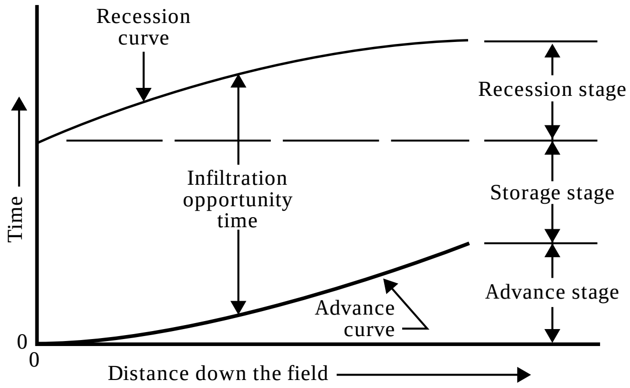


Table 6–1 Gross irrigation application, in inches [1/]

Net irrig depth (in)	- - - Application efficiency - - - (%)									
	80	75	70	65	50	55	50	45	40	35
0.40	0.50	0.53	0.57	0.62	0.67	0.73	0.80	0.89	1.00	1.17
0.60	0.75	0.80	0.85	0.92	1.00	1.09	1.20	1.33	1.50	1.71
0.80	1.00	1.07	1.14	1.23	1.33	1.45	1.60	1.78	2.00	2.29
1.00	1.25	1.33	1.43	1.54	1.67	1.82	2.00	2.22	2.50	2.86
1.20	1.50	1.60	1.71	1.85	2.00	1.18	2.40	2.67	3.00	3.43
1.40	1.75	1.87	2.00	2.15	2.33	2.55	2.80	3.11	3.50	4.00
1.60	2.00	2.13	2.29	2.46	2.67	2.91	3.20	3.56	4.00	4.57
1.80	2.25	2.40	2.57	2.77	3.00	3.27	3.60	4.00	4.50	5.14
2.00	2.50	2.67	2.86	3.08	3.33	3.64	4.00	4.44	5.00	5.71
2.20	2.75	2.93	3.14	3.38	3.67	4.00	4.40	4.89	5.50	6.29
2.40	3.00	3.20	3.43	3.69	4.00	4.36	4.80	5.33	6.00	6.86
2.60	3.25	3.47	3.71	4.00	4.33	4.73	5.20	5.78	6.50	7.43
2.80	3.50	3.73	4.00	4.31	4.67	5.09	5.60	6.22	7.00	8.00
3.00	3.75	4.00	4.29	4.62	5.00	5.45	6.00	6.67	7.50	8.57
3.20	4.00	4.27	4.57	4.92	5.33	5.82	6.40	7.11	8.00	9.14
3.40	4.25	4.53	4.86	5.23	5.67	6.18	6.80	7.56	8.50	9.71
3.60	4.50	4.30	5.14	5.54	6.00	6.55	7.20	8.00	9.00	10.29
3.80	4.75	5.07	5.43	5.85	6.33	6.91	7.60	8.44	9.50	20.86
4.00	5.00	5.33	5.71	6.15	6.67	7.27	8.00	8.89	10.00	11.43
4.20	5.25	5.60	6.00	6.46	7.00	7.64	8.40	9.33	10.50	12.00
4.40	5.50	5.87	6.29	6.77	7.33	8.00	8.80	9.78	11.00	12.57
4.60	5.75	6.13	6.57	7.08	7.67	8.36	9.20	10.22	11.50	13.14
4.80	6.00	6.40	6.86	7.38	8.00	8.78	9.60	10.67	12.00	13.71
5.00	6.25	6.67	7.14	7.69	8.33	9.09	10.00	11.11	12.50	14.29
5.20	6.50	6.93	7.43	8.00	8.67	9.45	10.40	11.56	13.00	14.36
5.40	6.75	7.20	7.71	8.31	9.00	9.82	10.80	12.00	14.00	16.00
5.60	7.00	7.47	8.00	8.62	9.33	10.18	11.20	12.44	14.00	16.00

1/ Includes deep percolation and tailwater runoff.

(b) Level basins, borders

This surface irrigation system uses relatively large flow rates supplied to level or nearly level soil surfaces over a short period of time. The basin (borders) may be any shape and is surrounded on all boundaries by a control barrier, such as a low dike or levee. The water is confined until infiltrated into the soil.

Level basins have been used for many years for irrigating orchards, citrus, grapes, alfalfa, small grains, and grass pasture. Similar to the level basin principal, contour levee irrigation has been used for centuries for growing rice.

Design of basin size depends on water supply flow rate, soil intake characteristics, and available soil water capacity. Basin irrigation can be adapted to most crops and certain marginal quality water not usable in other methods of irrigation. This system is best adapted for low to medium intake soils, where infiltration tends to be more uniform.

With proper design and management, level basin systems can result in high distribution uniformity and high overall application efficiency. Application efficiencies of individual irrigation events exceeding 90 percent can be obtained. Lack of uniformity in soil intake characteristics across the basin can reduce distribution uniformity of water infiltrated, as can using inadequate inflow rates.

(1) Advantages

- Level basin irrigation systems are the easiest to manage of any system. Application volume is controlled by inflow time of set, assuming inflow rate is known.
- Properly designed and managed level basin systems minimize deep percolation losses and high application efficiencies are attained. Distribution uniformity can be greatly improved over other irrigation systems. There is no runoff except for rice where flow through water is used to maintain the desired water surface elevation.
- Leaching saline, sodic, and other toxic ions is easier than with other methods. The reason for this is that water covers the entire soil surface uniformly and at a reasonably uniform depth. The water has the opportunity to infiltrate evenly, thereby reducing residual salts that often remain with graded border irrigation. Rainfall does not run off, so it can also be used for leaching. Leaching of toxic ions with level irrigation systems may not be as water efficient as leaching with sprinklers (unsaturated) because of some concentration of flow in macro pores.
- The guess work in applying the right amount of water is reduced since there is no surface runoff and nearly all water applied to a basin is infiltrated and used or lost to deep percolation within the basin.
- Relatively light applications of water are possible.
- Automation can be adapted as follows: The time of set, thus the amount of water applied, can be controlled directly with time clock operated gates in both head ditch and turnout(s) into a basin. However, with relatively large flows, powered gate control devices may require 110 volt power or a large battery(s). Drop open and drop close gates that are operated by gravity and water pressure against the head gate are available.
- Few turnout or outlet structures into a basin are needed.
- Except where rice fields are drained, no tailwater exists for further handling.
- Level basin areas as large as 10 to 40 acres can be irrigated when large streams are available and proper water control structures are used. Fields can be farmed using large equipment.
- Increased yields may result because more uniform amounts of water can be applied. Uniform distribution results in improved germination, improved plant environment, and more uniform growth. Leaching of plant nutrients is controlled. Knowledge of required application volume and timing is very important when using this irrigation system. Irrigation scheduling is discussed in Chapter 9, Irrigation Water Management.
- With operator-owned laser controlled equipment, annual maintenance or touch up can maintain fields in as designed condition. Laser controlled equipment can grade the surface to within about 0.025 to 0.05 foot of design elevation. Growers have discovered several advantages of annual laser controlled land leveling or planing, especially with grower owned equipment and with annual crops. Advantages of a near perfect system are realized every year instead of only the first year after leveling. Annual costs are about the same as re-leveling every 3 to 4 years.

(2) Limitations

- Precision leveling is required for uniform water distribution. If low or high areas exist, uneven infiltration occurs and distribution uniformity is reduced.
- Laser controlled leveling or surface planing equipment is almost essential to obtain uniform water distribution and high irrigation efficiencies.
- The correct amount of water must be applied. Over-application of water can lead to excessive plant inundation, high water temperatures that damage plants, leaching of nutrients, and the use of extra water. Too often when level basin irrigation systems are first installed, the irrigator tends to over irrigate, as 30 to 50 percent of water is no longer lost to runoff.
- To meet desirable basin size and shape objectives, earthwork volumes may be greater than for other surface irrigation methods.
- Variable soil intake characteristics within a single basin can create poor water distribution uniformity.
- Large basin inflow structures require erosion control measures. More than one inlet onto a field may be desirable.
- Typically, surface drainage must be provided to divert high rainfall events off the field.
- Relatively large streams of water are needed and should be used.
- If the surface drainage system does not release precipitation runoff in the natural drainage flow path, easements may be required.
- Some direct evaporation when irrigating low intake soils results because of excessive infiltration time (may be several hours). Also crop scalding can be a problem with some crops on low intake soils in very hot climates.

(3) Planning and design considerations

Factors to be considered in system design include:

- Intake characteristics of the soil can change throughout the season as farm equipment compacts the soil, from crop to crop, and from year to year.
- Large flow rates are desirable to maximize distribution uniformity of infiltrated water and basin size.
- Flow resistance of the crop affects the minimum flow needed to provide uniform flow depth and time of advance across the basin.
- Net application of water (depth in inches) can change as different crops are grown and as crop rooting depth increases during the season. Typically time is varied rather than flow rate.
- Available water capacity of soil in the actual plant root zone can vary because depth varies with root development.
- Topographic and soils characteristics of the site influence basin shape, earthwork required, and the size of basins and fitting basins within areas of uniform soils. Hydraulically, basins do not have to be rectangular. Often earthwork volumes can be reduced if nonrectangular shapes are used.

With this information, the length and width (or shape and size) of basins can be designed to obtain high distribution uniformity and acceptable application efficiencies. Basins that have the same size and shape are desirable, but not required.

In general, the entire basin should be covered by water in less than half of the total required irrigation opportunity time. For highest distribution uniformity, total coverage should take place within a fourth of the required irrigation opportunity time. This minimizes the effect of variability of soil intake rates and irregularities in the field surface.

To maximize distribution uniformity on basins, the inflow rate must be known, the design inflow time must be monitored, and water must be applied according to crop needs and soil conditions. Measuring delivery inflow is essential to knowing the inflow rate (Q). If a large delivery inflow is split into two or more flows for irrigation heads, additional measurement may be needed.

Carefully monitoring of design inflow time (T) is essential, especially when using large flows and short irrigation sets. For example, with inflow Q = 15 ft^3/s, and design opportunity time T = 35 minutes, an extra turn-on time of 10 minutes can increase the applied depth of water 29 percent. An extra turn-on time of only 5 minutes means an increase of 14 percent. Careless timing can change a season long irrigation efficiency from good to mediocre or poor quickly. The irrigator must change heads of water when needed rather than convenient. This is a big step in proper water management.

Applying water according to crop needs and in the amount the soil will hold maximizes irrigation water use.

(4) Design procedures

Basic design principles and procedures are described in NEH, Part 623 (Section 15), Chapter 4, Border Irrigation. Design procedures and examples provided in section 652.0605 are developed from state approved computer programs using existing methodology from chapters 4 and 5 of this guide or from ARS publication, *Surface Irrigation Model, SRFR.*

(c) Contour levee (rice lands)

Contour levee irrigation is similar to level basin irrigation except when growing rice. Water is retained by small dikes or levees that are constructed generally on the contour. Additional leveling may be required to square up fields or to widen the contour dike interval.

Where rice is grown, water is applied to the level or nearly level area (basins) between levees at a rate (in excess of the intake rate of the soil) to maintain ponding. Flow-through water is used to maintain a preselected water surface elevation; thus some tailwater may be occasionally discharged from the lowest basin. This water can contain undesirable chemicals.

Automated static non flow-through systems are being developed in some areas to reduce water use and downstream surface water pollution. These systems must consider water surface distortion by wind in addition to water surface evaporation and plant transpiration. Water surface sensors are used to monitor water depth in each basin. Two to four water surface sensing stations in each basin are recommended. When the water surface lowers to a predetermined level, signals are transmitted to a controller at an inlet structure to allow additional water to enter the basin.

(1) Advantages

- High irrigation efficiencies are obtainable on soils that have a very low intake rate.
- Maximum utilization of rainfall can be realized by maintaining water surface elevations slightly lower than flashboard crest elevations of water control structures.
- Uniform distribution of water and high application efficiency can be realized if flow-through water is minimized or reused.
- Runoff from rainfall can be handled with little additional structure requirement.
- Installation cost can be relatively low because land preparation is less where dikes and levees are installed on the contour. Size of areas between levees doesn’t need to be uniform.
- Simple water level control devices can be used. Automation at inflow structures to maintain a constant water level in the area between levees can reduce labor requirements and tailwater losses.

(2) Limitations

- Works best on soils that have a very low intake rate.
- Soils having restriction to vertical water movement, typically 18 to 30 inches below the soil surface, minimize water lost to deep percolation.
- Land grading is generally required to maximize area sizes between levees and provide a uniform depth of water. Land leveling can be substantial if it is desirable to make all basins the same size.
- Relatively large irrigation inflows are required to fill the basins. Flows larger than 5 ft^3/s with single inlet structures require erosion protection.
- Use is limited to soils with land slopes less than 0.5 percent.
- Residual pesticides can be carried downstream into public water through tailwater discharge.
- Surface drainage is required in high rainfall areas.

(3) Planning & design considerations

Design considerations are based on three critical periods of rice irrigation operation. They are flushing, flood establishment, and flood maintenance.

Flushing—A water supply should be available to flush the field between planting and flood establishment. To prevent seed development problems and plant stress, water should not remain on the soil surface for more than 3 days.

Flood establishment—Flood establishment is the application of water to inundate the soil surface to a planned depth. A maximum flood-up period of less than 6 days ensures uniform crop growth and maturity. Pump or diversion flow rates should be sufficient to provide a minimum of 1 inch of water depth above the highest point in the field, plus that needed for evapotranspiration during the flood-up period.

Flood maintenance—Flood maintenance is the application of water to maintain a planned water elevation in the area between levees. To maintain inundation, water must be added to replace crop evapotranspiration, lateral seepage losses of outside levees, deep percolation, flow-through water, and less effective rainfall for the period. Average daily evapotranspiration should be used for planning and design so that the flood is maintained during the most critical periods. Flow-through water should be minimized.

(4) Design procedures

Basic design principles and procedures are described in NEH, Section 15, Chapter 6, Contour Levee Irrigation, and in the Texas Rice Irrigation Guide.

(d) Level furrows

Level furrow irrigation is similar to both level basin and graded furrow irrigation. Laser controlled land leveling is required for highest irrigation uniformity. Irrigation water must be applied rapidly, using as large a stream as the furrow can contain, until the design volume or depth of irrigation is applied. Dikes along edges of each irrigation set can be used to contain water. The end of the furrow or field is blocked so the water is contained and ponded within each furrow. The same site conditions for level basins apply for level furrows. Level furrow irrigation is best suited to soils that have a moderate to low intake rate and moderate to high available water capacity.

(1) Advantages

- High application uniformity can be attained with a properly designed and managed system.
- Net irrigation application can be easily adjusted. Light applications can be applied where water can be introduced at both ends of the furrow or where outflow into a lower basin is allowed.
- There is no runoff from irrigation.
- This system is well suited to automation (see discussion of level basin and borders).
- Level basin (furrow) irrigation systems are the easiest to manage of all irrigation systems. Application volume is controlled by time, assuming the inflow rate is known.

(2) Limitations

- Except on uniform flat fields, extensive land preparation is required for initial installation.
- Typically, surface drainage must be provided to divert high rainfall events off the field.
- Set times are generally short requiring frequent changes.
- Relatively large streams of water are needed and should be used.
- Uniformity of the soil surface must be maintained. This essentially requires the use of laser controlled grading and planing equipment. (This is true with all surface irrigation systems.)
- Where land leveling activities (or natural conditions) expose soils with variable infiltration characteristics, infiltration uniformity can be poor.

(3) Planning and design considerations

Furrows should have adequate capacity for at least half the volume of the net irrigation application. Where it is undesirable to inundate a portion of the crop, or where the soil has low intake, the furrow cross section should be large enough to contain all the volume or depth of water applied per irrigation set.

(4) Design procedures

Basic design principles and procedures are described in NEH Part 623 (Section 15), Chapter 5, Furrow Irrigation, second edition. This chapter contains tables for a limited selection of field conditions. Computer programs are available that the planning technician can use to facilitate design. Design procedures and examples provided in section 652.0605 are developed from state approved computer programs using existing methodology from chapters 4 and 5 of this guide or from ARS publication, *Surface Irrigation Model, SRFR*.

(e) Graded borders

Graded border irrigation is a surface irrigation system where controlled surface flooding is used. The field to be irrigated is divided into strips of uniform width and grade by parallel dikes or border ridges. Each strip is irrigated separately. Water is introduced at one end and progressively covers the entire strip.

Irrigation of graded borders is a balanced advance and recession kind of water application. The borders (border strips) slope in the direction of irrigation, and the ends are usually open. Each strip is irrigated by diverting a stream of water onto the border at the upper end. The stream size must be such that the desired volume of water is applied to the strip in a time equal to, or slightly less than that needed for the soil to absorb the net irrigation amount required. When the desired volume of water has been delivered onto the strip, the stream is turned off. Water temporarily stored on the ground surface moves down the strip to complete the irrigation.

Uniform and efficient application of water depends on the use of an irrigation stream of proper size. Too large a stream results in inadequate irrigation at the upper end of the strip and often excessive surface runoff at the lower end. If the stream is too small, the lower end of the strip is inadequately irrigated and the upper end has excessive, deep percolation. Chapter 9, Irrigation Water Management, discusses procedures to evaluate an irrigation event and develop necessary adjustments in flow and time of set.

(1) Advantages

- Water with relatively high suspended sediment loads can be used.
- Graded borders can be used in rotation with other methods and systems of applying water including sprinkler and furrow irrigation systems.
- With proper system design and maintenance, this method requires relatively little labor. Labor can be further reduced by system automation.
- With properly designed and maintained systems and proper management, relatively high application efficiencies can be obtained on medium intake rate soils.
- Distance between border dikes can be set to fit existing cultivation and harvesting equipment. Properly designed and constructed dikes can be crossed by equipment.

(2) Limitations

- Must have sufficient depth of soil after land leveling for growing crops.
- To attain the best distribution uniformity, frequent observation (or automation) is required to shut off water at required times. Advancing temporary surface storage completes irrigation of the lower part of the border.
- Relative uniform topography is required to allow needed land leveling.
- Each border strip should have little or no cross slope.
- Slope should be uniform in the direction of irrigation with no reverse slope.
- A moderate level of irrigator skill and management is required.
- Uniform light applications of water are difficult to apply.

(3) Planning and design consideration

The following factors must be considered in the design of a graded border system. When this information is known, the border width, initial flow rates, and inflow times can be determined. Factors for consideration are:

- Intake characteristics of the soil
- Available flow rate
- Flow resistance of the crop to be grown
- Quantity (depth) of the water to be applied
- Water quality
- Slope
- Erodibility of the soil
- Available water capacity of soil in actual plant root zone (depth varies with root development)

As a general rule for a properly designed and managed graded border system, water should be shut off when the wetting front has reached two-thirds to three-fourths of the border strip length. Detailed designs are based on estimates of intake rates, net water application, crop flow restriction (roughness coefficient), erodibility of the soil, and net water application. All these factors are variables even on the same soil type and the same field. For this reason designs must allow for adjustments of flow rates, application times during system operation, or both. Some growers choose to deficit irrigate lower portions of the field to conserve water, reduce set time, and limit runoff.

Slope in the direction of irrigation should not exceed the following:

Arid & semiarid		- - - - Humid - - - -	
non-sod	sod	non-sod	sod
2 %	4 %	0.5 %	2 %

(4) Design procedures

Basic design principles and procedures are described in NEH, Part 623 (Section 15) Chapter 4, Border Irrigation. Design procedures and examples provided in section 652.0605 are developed from state approved computer programs using existing methodology from chapters 4 and 5 of this guide or from the ARS publication *Surface Irrigation Model, SRFR.*

(5) Modifications to graded border systems

Border surge (characteristics and design considerations)**—**The general principles of surge irrigation work with graded borders the same as they do with graded furrows. The surge irrigation technique works best where the soil infiltration rate needs to be reduced (i.e., medium to coarse textured soils). Surge irrigation can be used to reduce both the net and total depth of irrigation water applied. (See discussion of furrow surge irrigation procedures later in this chapter.) The main difference is that an automated system capable of surging larger volumes of water to a single border is required. This generally requires large gated pipe or multiple risers. Developing equipment to automate ditch turnouts has been attempted, but such equipment is not commercially available at the time of this writing. Border surge can also be accomplished by using a surge valve to split the water between two adjacent borders via open ended pipelines and short ditches.

Border cablegation (characteristics and design consideration)—Cablegation is an excellent way to automate graded border systems providing the slope (fall) along the head ditch or supply pipeline is adequate. Approximately 0.2 foot per 1,000-foot grade is required on the supply pipeline at head ditch location. See discussion of furrow cablegation irrigation procedures later in this chapter. Large diameter gated pipe is generally required to handle the larger inflows needed for borders than that needed by furrows. This is a good way to provide accurate inflow times for short borders that would otherwise take frequent visits by the irrigator. One advantage with cablegation is that inflow times are easily changed by a simple adjustment of the cable speed controller. Water application design procedure is the same as for a manually operated system.

(f) Graded furrow characteristics

Graded furrow irrigation is a surface irrigation system that applies water to the soil by allowing water to flow downslope, in evenly spaced channels called furrows, rills, or corrugations. These small channels convey water down the field to the plants either growing in the furrows or on beds between the furrows. Graded furrow systems differ from border irrigation in that only part of the ground surface is covered with water. Water enters the soil by both vertically downward and lateral infiltration. The furrow stream is applied until the desired application depth is obtained. The time that water must be supplied to furrows is dependent upon the volume of water required to refill the soil profile to the desired irrigation depth. The intake rate of the soil, spacing of furrows, and length of the field all affect the amount of water to be applied. Surface grading (land leveling) to provide uniform slopes is essential to permit uniform water application and efficient irrigation.

Furrow irrigation also includes applying water with corrugations. Corrugations are typically used to irrigate noncultivated close-growing field crops using small closely-spaced channels directed down the primary slope of the field. Corrugations are also used to help guide irrigation streams in border strips. In this case the design is based on the border design procedures instead of the furrow method. Corrugations are frequently formed after the crop has been seeded, such as with small grains. In case of a perennial crop, such as alfalfa, they are reshaped as needed to maintain the desired channel cross section. Water application principles are the same as for furrow, with spacing, size, shape, and retardance characteristics being the primary differences. Corrugation stream sizes are small in comparison to furrow streams, and lengths of run are relatively short because of the smaller flows generally used and the resistance to flow caused by the growing crops.

Current ARS research and academia support the zero-inertia theory of surface irrigation, especially with furrow irrigation in lieu of the process in NEH, Part 623 (Section 15) Chapter 5, Furrow Irrigation.

(1) Advantages

- The number of furrows irrigated at one time can be adjusted to match available water delivery. Adequate inflow to each furrow should always be used.
- Uniform application can be obtained if adequate management practices are followed and the land has been properly prepared.
- Initial capital investment is relatively low on lands not requiring extensive land leveling. The furrows and corrugations are constructed by readily available and commonly used farm implements.
- Water with relatively high suspended sediment loads can be used.

(2) Limitations

- Water erosion hazards may be high, depending on field slope and soil texture. Erosion is of increasing concern as farm managers become more aware and as controls are placed on the amount of sediment that may leave the field and enter public water bodies.
- Tailwater (runoff) is nearly always required by graded furrow irrigation to provide uniform or adequate irrigation in the lower part of the field.
- To get adequate water infiltrated in the lower end of the field, the upper end is almost always overwatered resulting in deep percolation losses. Graded furrow system modifications, such as tailwater reuse, surge, and cablegation, can minimize deep percolation losses.
- Salts from either the soil or water supply can concentrate on ridges and beds. This can be a problem during seed germination and early stages of plant development even with salt-tolerant crops. Planting on ridge slopes and good water management help minimize this limitation.
- With some low and high intake soils and wide planting beds, lateral spread of water may not be adequate to provide complete irrigation across the bed in a reasonable irrigation time.
- With high intake soils the difference in intake opportunity time along the furrow, because of the time required for the stream to advance, can make it difficult to obtain high distribution uniformity. Furrow irrigation system modifications, such as tailwater reuse, surge, and cut back, can minimize nonuniformity.
- Furrows and corrugations create a rough field surface, which is inconvenient to cross with farm equipment.
- Labor requirements are high because irrigation streams must be carefully regulated to achieve uniform advance and infiltration. Intake rate varies with each furrow because of tillage equipment compaction (soft versus hard furrow, or wheel versus nonwheel furrow) and can require adjustment of inflows in all furrows during the set. Adjustments of water inflow may be necessary several times during the set to maintain uniform advance rates in all furrows.
- Adequate leaching of salts is more difficult than with borders or sprinkler systems.
- Land leveling and preplant land grading or planing is normally required to provide uniform furrow grades.

(3) Planning and design considerations

Factors that must be considered in graded furrow design include:

- Intake characteristics of the soil (or advance rate of known inflows).
- Erodibility of the soil.
- Available water supply.
- Depth of water to be applied each irrigation.
- Furrow spacing (distance between furrows in which water will be introduced). This is quite important when the irrigator is using inflows to alternate furrows.
- Field slope in direction of irrigation and cross slope.
- Length of furrows.
- Flow resistance of crop to be grown.
- Available water capacity of soil in plant root zone (depth of root zone varies with root development).

With this information the flow rate per furrow and inflow time can be designed for desirable uniformity. Amounts of deep percolation below the crop root zone and runoff can be estimated.

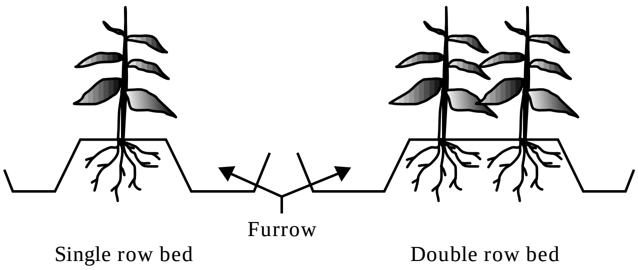
Optimum distribution uniformity for a given system occurs when uniform grade is in the direction of irrigation. Typically a constant flow rate is turned into the furrow for the entire irrigation set. Flow rates and set times are designed to provide a desirable net application depth for a planned length of furrow. Runoff is essential beyond that part of the field receiving adequate irrigation. Runoff from the field can be reduced where deficit irrigation is planned and can be tolerated by the crop in the lower part of the field. Seasonal changing of soil intake characteristics requires adjustments in inflow rates and time of set.

Normally, one furrow is between each crop row except for some bedded crops where two or more crop rows are planted on each bed. In these cases the furrows are along each pair of crop rows. See figure 6–2. The size (width and depth) of furrows and the spacing between rows depend on: the soil type, the crop, local cultural practices; and, on cultivation and harvesting equipment. Spacing of gates on gated pipe and setting of siphon tubes should match furrow spacing on field crops.

(4) Design procedures

Basic design principles and procedures are contained in NEH Part 623 (Section 15), Chapter 5, Furrow Irrigation and in ARS publication, *SRFR, A computer program for simulating flow in surface irrigation, Furrows-Basins-Borders* (WCL Report #17 1990). Planning technicians can use design charts where they have been prepared, do the calculations by using a small calculator, or by use of a computer. Many programs have been developed for computer use. One is the ARS model, SRFR. See section 652.0605 for design procedures and examples.

Figure 6–2 Typical furrow and bed arrangement for row crops



(5) Modifications to graded furrow irrigation systems

Several modifications to graded furrow irrigation systems can improve uniformity of applied and infiltrated water and increase application efficiency. Some are quite easy and cost effective to automate. These modifications will be described individually as design procedures and field application techniques apply to each. The modifications include:

(i) Graded furrow with cutback of inflow—In this type of furrow system, a large flow of water is initially turned into the furrow. When the water has nearly reached the end of the furrow, the inflow rate is reduced, or cutback. This procedure can increase uniformity of infiltrated water throughout the furrow length and reduce runoff. This modification has not had widespread use because of the additional labor required to manually reduce the flow rate and then reset the extra water that becomes available from the cutback. Cutback and resetting new water requires continual diligence by the irrigator to keep up with the new turn-on and turn-off times. The cablegation technique was developed as an attempt to automate cutback systems.

Most surge irrigation equipment has options available for multiple half cycle times, for use when the water advance reaches the end of the field. This "soak cycle" approximates a cutback system.

The following guidelines provide a practical procedure:

- Cutback initial flow when water reaches about three-fourths of the distance down the furrow.
- The inflow rate is typically reduced to half the initial rate.
- The reduced inflow rate should be applied until the desired application amount is reached.

Design procedures—Basic design principles and procedures are discussed in NEH, Part 623 (Section 15), Chapter 5, Furrow Irrigation. Design procedures and examples provided in section 652.0605 are developed from state approved computer programs using existing methodology from chapters 4 and 5 of this guide or from ARS publication, *Surface Irrigation Model, SRFR.*

***(ii) Graded furrow with blocked ends*—**This modification to graded furrow irrigation has the potential to reduce or eliminate runoff and to improve water distribution uniformity and application efficiency. The ends of furrows are blocked, thereby ponding occurs in the lower part of the field. A tailwater ditch can be used to cause reverse flow in those furrows where water has not reached the end of the furrow. Infiltration is increased in this lower end. For best water distribution uniformity, blocked end furrow irrigation systems should pond water on the lower fourth to third of the field. Care must be exercised not to flood the plants in this area if they will not tolerate inundation.

Since runoff is eliminated, potential pollution from nutrients and pesticides to downstream surface water can also be substantially reduced. However, all the applied irrigation water is now infiltrated, thereby increasing the potential for pollution of ground water. Often blocking furrow ends only trades runoff for deep percolation loss. When converting to graded furrows with blocked ends, adjustments to inflow rates and possibly set time are essential. Inflow rates and set time are typically reduced. Blocked end furrow systems work best on low gradient fields.

Advantages:

- Eliminates runoff.
- Application uniformity can be increased.

Limitations:

- **L**imited to field slopes where the backed up or ponded area is between a fourth and a third of the length of the field.
- Furrows must have a large enough cross section to contain the ponded water.
- An increase in labor is required to watch and adjust inflows to match advance and infiltration in all furrows and prevent dike overtopping at the lower end.

Planning and design considerations:

The volume of water delivered to the furrow is equal to the average intake over the furrow length. The design of a graded furrow with blocked ends is similar to that for a level furrow in that the volume of inflow needed to provide the desired amount of application is provided to the furrow. Difficulty comes in accounting for and adjusting inflows for individual furrow intake characteristics; i.e., hard versus soft furrows.

Design procedures:

Basic design principles and procedures are presented in NEH, Part 623 (Section 15), Chapter 5, Furrow Irrigation, for level furrows. See section 652.0605 for design procedures and examples.

***(iii) Graded furrow with modified slope*—**Slope modification to graded furrow irrigation has the potential to increase uniformity of infiltrated water. The two types of slope modification are:

- Slope that is gradually reduced throughout the entire length of the field.
- Slope that is graded in the upper part of the field and level in the lower part.

In the first type, slope in the direction of irrigation is gradually reduced throughout the full length of the field. Theory is to obtain a more uniform opportunity time for infiltration throughout the furrow length. Increased grades at the upper end decrease advance time for water to reach the lower part of the field. The irrigator must adjust inflow rates to create a uniform advance in all furrows. Adjustment throughout the season is also usually required.

In the second type, slope in the direction of irrigation can be divided into two parts—a graded upper field and a level lower field. Irrigation tailwater runoff from the sloping upper field irrigates the lower field. Slope changes typically occur at one-half, two-thirds, or three-fourths of the total furrow length.

Modified slope furrow irrigation systems can have some of the highest distribution uniformities of any system. However, they also require the most intense water management.

Advantages:

- High potential for increased irrigation uniformity.
- Limited (or eliminated) tailwater runoff.
- Decreased deep percolation.

Disadvantages:

- Higher irrigator skill and labor are required.
- Adaptable only on certain topographic locations.
- Most difficult of all irrigation systems to manage.
- Works best for design conditions.
- Requires adjusting furrow inflow rates throughout the season and from year to year.

Design procedures:
Design each slope section as a separate field. Except for the upper most field where the water supply is in a head ditch or pipeline, tailwater runoff from the higher elevation field is the furrow inflow for the next lower field. Because of changing intake characteristics both seasonally and yearly, furrow inflow is difficult to project for the lower fields. Typically lower value crops are grown on the lowest field.

Planning and design considerations are the same as those for graded furrow.

(iv) Contour furrow—Where downslope irrigation grade is excessive, the direction of irrigation furrows can be turned cross slope or on the contour. This will reduce the furrow grade. Unless the field slope is quite uniform, irrigation grades can be variable; a factor that tends to reduce distribution uniformity, application efficiency, and to increase runoff. On moderately sloping land, a principal concern is the possibility of furrow streamflows breaking across ridges or beds. This is more of a problem with crops, such as onions and beans, where shallow furrows are used or where surface residue is in the furrows. Where large water supplies are available and land slope is nearly level, furrows can be directed across the slope to convert a graded furrow irrigation system to a level furrow system. This often delays land leveling cost by several years.

Advantages:
- Irrigation grades are decreased.
- Erosion can be reduced.
- Can be used on field slopes that exceed desirable irrigation grade.
- Can minimize or delay land preparation costs.

Limitations:
- Point rows may result where field slopes are not uniform.
- Head and tailwater ditches may be on erosive grades.
- Overtopping during precipitation events can increase erosion.
- High irrigator skill and labor are required.
- Not suited to areas with high intensity rainfall events unless adequate provisions are made to control erosion.

Design procedures:
Design procedures for a contour furrow system are the same as those for graded furrow.

(v) Level furrow—Furrows are on nearly flat or level grade. A constant flow rate is turned into each furrow for the entire irrigation set. Flow rates and set times are designed to provide a desirable net application depth for a planned length of furrow. There is no runoff. Where the tail end of furrows is connected with a ditch, outflow from the faster advancing furrows can enter adjacent furrows from the tail end. This can improve uniformity of infiltration throughout the field. Total fall in the length of run cannot exceed half the net depth of application.

Advantages (see section 652.0601(d):
- High application uniformity can be attained.
- Net irrigation application can be easily adjusted.
- There is no irrigation runoff.
- Well suited to automation.
- Easiest to manage of all irrigation systems.
- With a uniform water supply, time of set determines application amount.

Limitations (see section 652.0601(d):
- Except on uniform flat fields, extensive land preparation is required for initial installation.
- Providing surface drainage in moderate to high rainfall areas is essential.
- Set times are generally short requiring frequent changes.
- Relatively large streams of water are needed and should be used, otherwise infiltration uniformity can be poor.
- Uniformity of soil surface must be maintained.

(vi) Graded furrow using surge technique—
Surge irrigation is the intermittent application of water to furrows or borders creating a series of on-off periods of either constant or variable time intervals. Usually the water is alternated (switched) between two irrigation sets at predetermined, often varied time increments until water has advanced to the end of the field or until irrigation is complete. Surge has the potential, with good management, to significantly decrease deep percolation and runoff, and significantly improve infiltration uniformity. Under some conditions it can reduce furrow erosion. Surge irrigation is most effective on fields where it is desirable to reduce soil intake rate.

During the first *on* period, the inflow wetting front advances down the furrow some distance, typically 20 to 25 percent of the furrow length. During the *off* period, water is applied to a second furrow typically on a different set. Each time water is turned on, it progresses more rapidly across the wetted area. More flow is then available to progress further down the dry furrow. The increased advance is caused by the decrease in water intake rate in the previously wetted area and decreased furrow roughness. By alternating flows in furrows, the total advance time and volume of water applied are both reduced when compared to standard continuous flow methods. Generally, surging results in more uniform water infiltration throughout the length of the furrow. Figure 6–3 illustrates how surge flow compares with conventional steady flow furrow irrigation methods.

Irrigation water can be surged manually to reduce the required advance time to the end of the field. These high labor systems are typically used on recently tilled soils and on soils that crack when dry.

Some irrigators use surge as a labor saving device, operating two irrigation sets with each water change. Because half the water is applied to each irrigation set, total set time may need to increase to provide an adequate irrigation. Where overirrigation has occurred in the past, less water is applied at better uniformity within the same set time.

Once the advance phase is complete, surge valve time interval can be set to provide a cutback irrigation inflow (short equal time intervals on each side). Some refer to this action as a soak cycle. Typically runoff is reduced without sacrificing irrigation uniformity down the furrow.

The system uses a battery powered, timer controlled valve that controls the direction of the irrigation flow. This is usually accomplished with a butterfly type valve as illustrated in figure 6–4. Solar powered panels are available for battery charging. Programmable controllers are also available. The control valve alternately directs the irrigation head to flow in opposite directions from the valve, usually in gated pipe. Modifications have been adapted for use on open concrete lined ditches using gated ports.

Advantages:

- Generally less water is used, distribution uniformity is increased, deep percolation at the upper end of the field is decreased, and overall application efficiency is increased.
- Surging times can be easily adjusted when using timer flow control valves.
- Small application amounts can be applied.
- Where water is pumped, energy use can be reduced.
- Overall, deep percolation and runoff can be reduced.
- One controller can be moved from site to site to operate additional valve bodies.

Limitations:

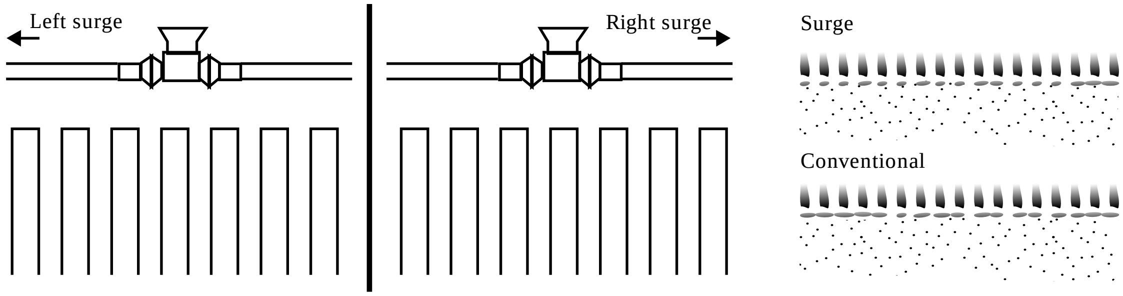
- Normal opening and closing of valves for surging is not practical for manual operation. However, manually operated long surge cycles on cracking clay soils may be advantageous.
- Care must be taken to assure adequate water is being applied, especially at the lower end of the field.
- Additional cost is associated with surge valve(s) and controller(s).
- When surge equipment is used on clay and clay loam soils, careful management is necessary to avoid excessive field runoff, especially if adequate water is applied to the plant root zone at the lower end of the field.

Planning and design considerations:

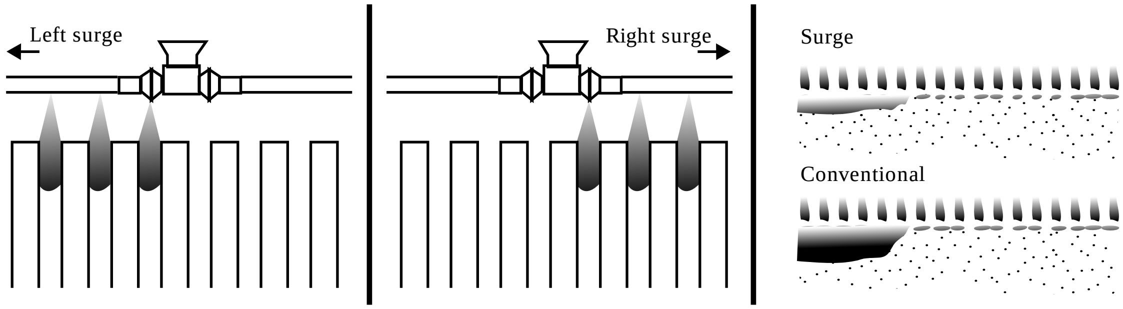
For many soils, experience has been that the same stream size under surge flow advances to the end of the field on both sets in nearly the same amount or less time it takes one conventional set in continuous flow. Flows advance to the end of twice as many furrows with the same amount of water and time. Surge flows allow light irrigations to be applied more efficiently (for germination of new crops, for crops with shallow root systems, and between rainfall events in semiarid climatic regions).

Many existing gated pipe systems can be converted to surge. Depending on existing outlets from a buried pipe system (or from a head ditch), layout of gated pipe for a surge system may be relatively easy. Perhaps only surge valves are needed. Solar battery powered, time clock controlled, commercial valves are readily available. Valve controllers that can be programmed in variable surge times during the advance

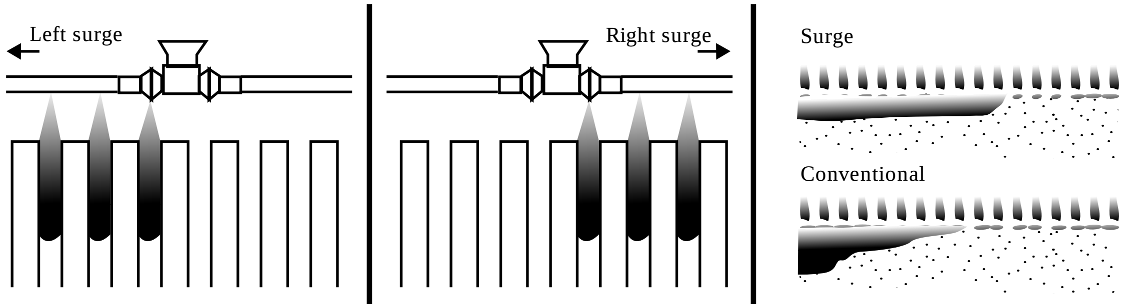
Figure 6–3 Surge irrigation versus conventional continuous flow furrow irrigation



End of first surge cycle



End of second surge cycle



End of third surge cycle

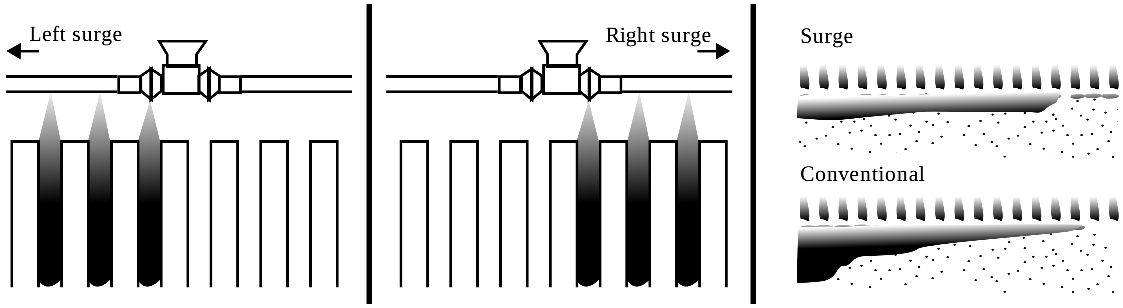
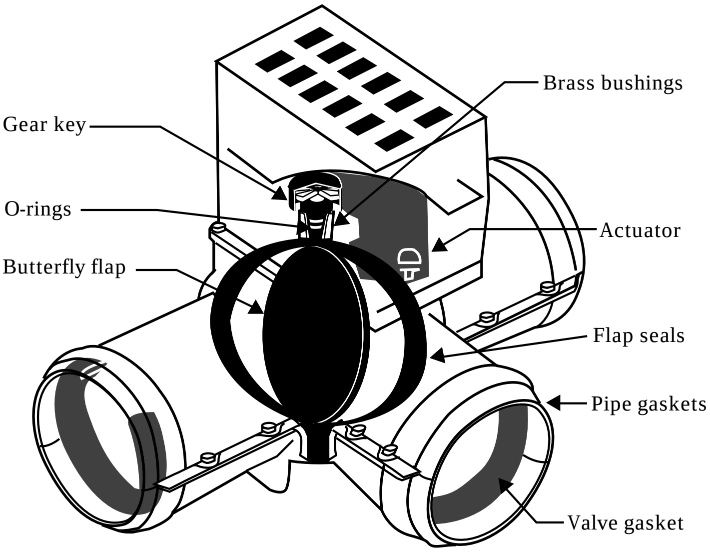
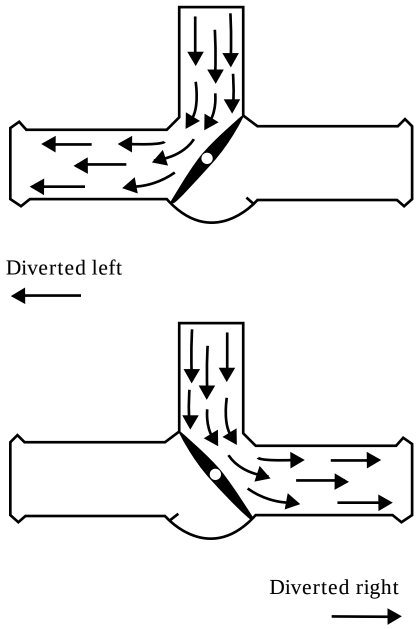


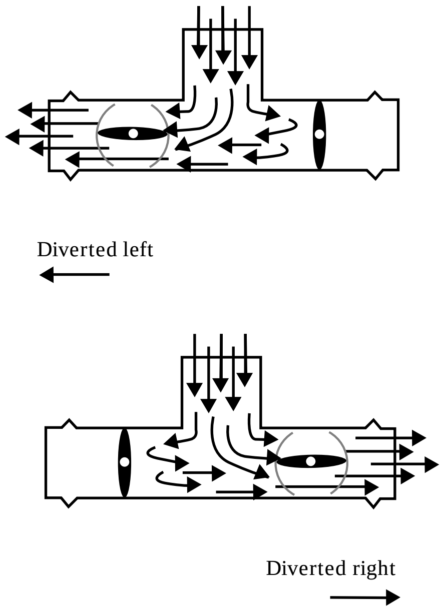
Figure 6–4 Butterfly type surge valves



Single butterfly type valve



Double butterfly type valve



cycle are recommended. They should also be programmable for short duration surges after the water has reached the end of the furrow. This type of valve allows maximum flexibility in managing surge irrigation.

Sometimes costs and labor can be reduced by using several valve bodies with one controller. This allows leaving the valve bodies and gated pipe in place across the field(s) during the season, or with an extra valve body, the next irrigation set can be readied while the existing set is in operation. Only one controller is moved from place to place when each irrigation set is started.

Surge flow irrigation requires a greater level of management skill than conventional furrow irrigation. Most irrigators need assistance when first operating a surge system. They need to be able to observe the progress of each irrigation during different parts of the irrigation season as infiltration changes and to make the appropriate adjustments in surge times and flow rates. Field observations and evaluations of each irrigation application can help in fine tuning surge cycling times. Adjustments to gates are necessary to maintain uniform advance in all furrows. Screening of irrigation canal and reservoir water is necessary to limit debris from partly plugging valves and gates in gated pipe. Constant and uniform flow from gate openings is essential throughout the irrigation set.

Alternative methods for providing proper on-times include:

- Variable time-constant distance advance, variable cutback time method—This method varies the times of surges advancing in the furrow and the time of surges after water reaches the end of the furrow. Time adjustments can often be made so water in the furrow never quite recedes during a surge, yet runoff is kept very low.
- Variable time-constant distance advance, constant cutback method—This method varies the times of surges advancing in the furrow and uses a constant time for surges after water has reached the end of the furrow. This method may be most beneficial with moderate to high intake soils.
- Constant time-variable distance method—This method is used when the surge controller cannot automatically utilize variable surge times.

When using any of these methods, the planning technician and irrigator must realize that to apply the same amount of water, the surge sets need to be allowed to run longer than they previously ran to irrigate the same area. This is true unless only a light application is desired, and is especially the case when irrigating low intake soils.

Design procedures:
Design procedures and examples provided in section 652.0605 are developed from state approved computer programs using existing methodology from chapters 4 and 5 of this guide, or from ARS publication *Surface Irrigation Model, SRFR.*

(vii) Graded furrow using cablegation technique**—**This modification to graded furrow irrigation can potentially decrease runoff, increase uniformity of infiltration, and decrease labor required. A plug inserted inside a gated pipe at the head ditch location is pushed slowly downslope through the pipe by water pressure. As the plug moves past the gates, water flows out the gates. Furrow flow (gate discharge) gradually reduces until the free water surface in the gated pipeline is lower than the gate opening. The plug is restrained by a small cable or rope attached to a hydraulic or electric braking device located at the head end of the gated pipe. The speed of the cable controls the time of set and depth of application. Cablegation has some of the same benefits as cutback irrigation. Maximum furrow inflow occurs at the beginning of irrigation as the moving plug clears the opened gate. Figure 6–5 illustrates the general arrangement of controls, pipes, and outlets in a cablegation system. Large gates, or risers on a buried pipeline, can be used to irrigate borders.

Advantages:

- Reduces labor. The system is essentially an automated gated pipe system.
- Easy to adjust speed of plug (irrigation set time).
- Improves distribution uniformity. Can reduce runoff and deep percolation.
- Variable grades along the gated pipe can be accounted for.

Limitations:

- Precise grade is required for gated pipe to achieve uniformity of gate discharge (furrow inflow).

- Screening to remove trash in the irrigation water is necessary.
- Some water is lost because of bypass requirements as the first few furrows in the set are irrigated and the plug has moved far enough to allow water to discharge from all outlets.
- Cablegation works best where gated pipeline grades are between 0.2 and 2.0 feet per 100 feet (0.2 to 2.0%).

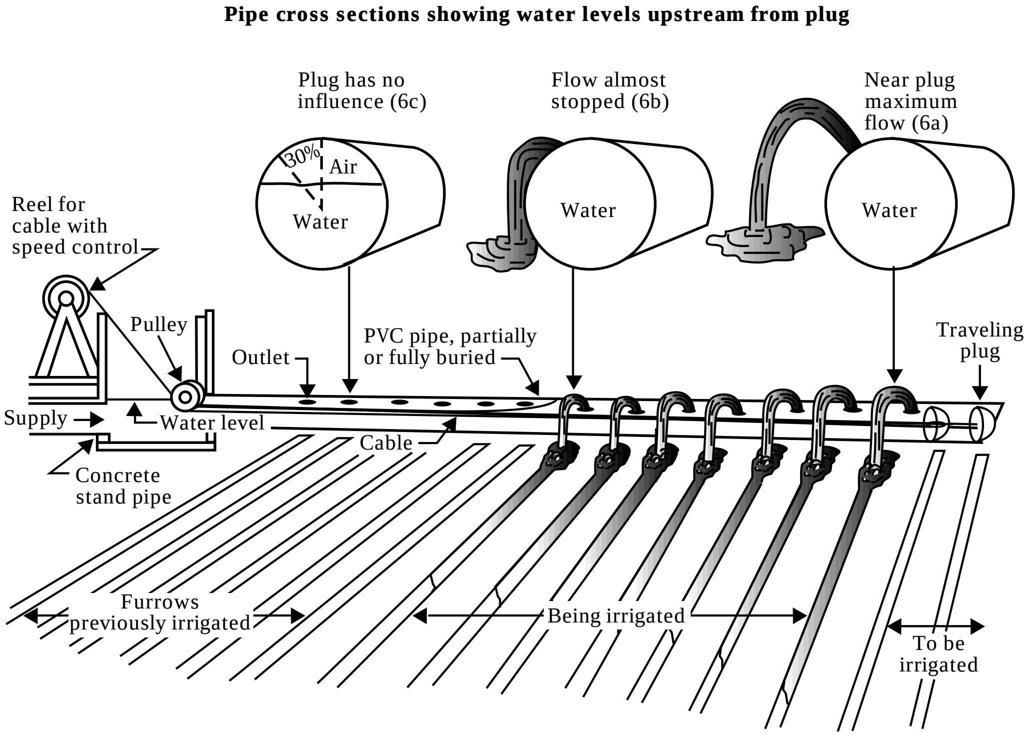
Planning and design considerations:
A single pipe is used to transmit water along the upper edge of the field and to distribute equal amounts to furrows or borders. The pipe is sized large enough to carry the head of water at the head ditch grade without completely filling the pipe (partial pipe flow). The plug causes water from the supply source to fill the pipe and flow out the outlets. See figure 6–5.

In this figure, the outlets (a) nearest the plug have the greatest pressure head; therefore, the greatest outflow. As the plug moves down grade, the pressure head decreases for any one gate causing the outflow to decrease (b). This process continues until outflow ceases because the outlet is above the water level in the pipe (c).

Partial pipe flow condition is essential for cablegation to function. Once gates are adjusted for the desirable furrow flow, adjustments for following irrigations are seldom necessary.

Shortly after the plug reaches the end of the pipe and the last furrow has been irrigated the desired amount of time, water is shut off and the plug is removed by removing a cap on the end of the gated pipe. The cap

Figure 6–5 General arrangement of controls, pipe, and outlets



is replaced and the cable rewound onto the winch. The plug is reattached to the cable at the head of the pipe ready for the next irrigation. Water brakes, hydraulic rams, or electrical winch devices control the speed of the cable and plug. The water brake is a low cost, but very effective, water powered device. See ARS publication ARS-21, *Cablegation Systems for Irrigation*, for details of speed control devices. Rewinding of the cable is generally done by hand.

Design procedures:
Design methodology is reviewed in ARS publication ARS-21, *Cablegation Systems for Irrigation*, and several supplements published in recent years reviewing current research. Design procedure and examples are presented in section 652.0605.

(viii) Graded furrow with tailwater reuse (pumpback)—This modification to graded furrow irrigation can increase overall field application efficiency since most of the runoff or tailwater is returned to the head of the same field or to a lower elevation field for reuse. Furrow inflow rates are generally higher for decreased advance times and improved distribution uniformity. The components of a tailwater reuse (pumpback) facility includes tailwater collection ditches, a pumping plant with sump, pipeline(s), and a holding pond at either the lower end or the head end of a field or farm.

Advantages:

- Offsite runoff is decreased, thereby decreasing potential pollution of other surface water.
- Wastewater is available for irrigation or other on-farm uses.
- Better utilization of water delivered to the farm.
- Furrow irrigation application uniformity is increased.
- Soluble chemicals contained in tailwater are reapplied to cropland.

Limitations:

- Irrigated cropland is often taken out of production for the reservoir or sump. Many times ponds can be located in odd shaped corners that are not farmed.
- Flow to downstream users depending on runoff is reduced.
- Depending on chemical application and management, runoff can contain high levels of nutrients and pesticides. This can create a potential hazard to wildlife, especially water fowl that are drawn to ponded water.

Planning and design considerations:
Items to consider for this type of system are topography and layout of irrigated fields and the irrigators management level and desire. Figure 6–6 displays a typical tailwater recovery and reuse system in conjunction with an underground distribution pipeline.

Where the holding pond is located at the head end of the field or farm, only a small pumping plant and pump sump are required at the lower end. This alternative allows the pumping of tailwater as it occurs. The peak flow used to size the pump is generally less than half of the irrigation inflow, and a smaller diameter pipe is needed. The pump can be cycled or have float control switches that automatically turn on and turn off the pump as runoff collects in the sump, or it can be set to run continuously during the runoff period. Regardless where the holding pond is located, it should have the capacity to store runoff from one complete irrigation set.

Where siphon tubes, spiles, or ditch turnouts are used, cutback irrigation can result when water is returned to the supply ditch only during the first half of the irrigation set. While pumping back to the presently used head ditch, the water surface in the head ditch raises, causing siphon tube, spile, or turnout discharge to increase. This is generally undesirable. Where storage is inadequate, additional furrows must be set to use the pumpback water. Where gated pipe is used, pumpback flows are generally uniform and constant during the irrigation set. Additional gates are opened to discharge the pumpback water. To reduce labor and odd irrigation set times, it is typically easier to use the pumpback water on new sets. However, storage to contain runoff from one complete irrigation is necessary.

Where erosion is present, a small, shallow sediment settling basin should be installed just upstream of the sump pump or inlet end of the holding pond. A shallow basin can be cleaned relatively easily with available farm machinery, while a large pond or pit may require cleaning with large construction type equipment.

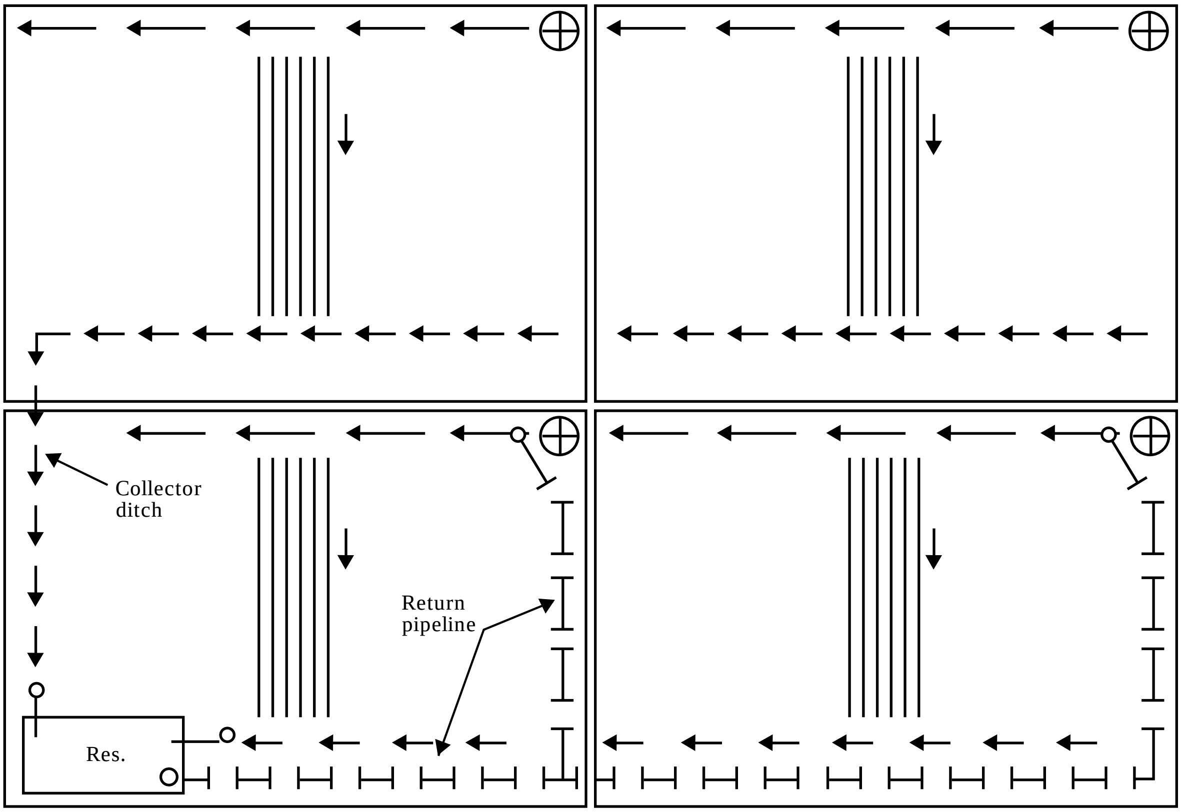
Erosion should be minimized with proper design and installation of collection ditches and sump or pit inflow structures. Irrigation tailwater should enter the sump or pond in a protected inlet structure (i.e., pipe drop inlet) at or near the pump inlet. Suspended silts and clays are then pumped back onto the field.

Tailwater collection ditches excavated below furrow outlet grade are the major cause of erosion when furrow irrigating highly erosive soils. Furrow outflow is often allowed to drop several inches into the tailwater collection ditches. An erosion headfall develops and works its way upstream in the furrow. This condition effectively removes soil and carries it into the tailwater collection ditch. Narrow vegetative strips (10 to 15 feet wide) and hand placed straw in the furrows just upstream of the tailwater collection ditch are effective means to control this type of erosion. Buried pipelines with risers at furrow grade can also be used.

Many pumps are available for use in tailwater recovery facilities. Tailwater runoff can contain suspended sediment, plant debris, worms, insects, and farm chemicals. Either sufficient screening is required to keep the material out of the pump, or a pump is selected that can handle the material. Pumping heads are generally low; therefore, horsepower requirements are generally low. Electric power is preferred to drive pumps because tractor and diesel engines are typically overpowered. However, for limited use a farm tractor may be desirable.

Tailwater reuse facility design requires reasonable estimates of runoff rate and volume. A field evaluation can be provided for an irrigation event to estimate the runoff, or runoff can be measured. A field evaluation or tailwater flow measurement should be made during periods of maximum expected tailwater runoff (i.e., second irrigation after furrows are smoothed by previous irrigation and before maximum crop water use).

Figure 6–6 Typical layout for a tailwater recovery and reuse facility



Measurement of runoff is relatively easy using portable measuring weirs, flumes, or small orifice plates. Seepage, evaporation, and overflow losses occur in the recovery, storage, and transport of tailwater. Losses can be as high as 25 to 35 percent of the runoff volume depending on the many variables and management skills of the irrigator.

Design procedures:
See Chapter 7, Farm Distribution Components, for additional discussion, design procedures, and examples.

(g) Contour ditch

Contour ditch is a form of controlled surface flooding. This system consists of installing a series of irrigation ditches or gated pipe running across the slope on the contour with little grade (< 0.1 ft per 100 ft). Water is discharged with siphon tubes, from gated pipe, or allowed to flow over the banks of the contour ditch uniformly along the length of the irrigation set. Generally, no flow constraints, such as dikes or levees, are along the length of run. In theory the water moves down the slope as a uniform sheet, but in practice it generally does not. The flow mostly moves to low areas and becomes nonuniformly distributed. Runoff is collected in the next downslope contour ditch and redistributed. Pasture and hay are the crops typically grown. Corrugations can be used to help irrigation flows.

The spacing between the ditches is governed by topography, soil intake rate, and net irrigation application. This type system is applicable to slopes up to 15 percent. On slopes of more than 2 percent, it should be restricted to sod forming crops. This system is adaptable to the steep residual soils in foothill areas and is generally used where season long water is not available at a reasonable cost.

(1) Advantages

- Contour ditch is low in establishment costs, requiring very little field preparation. However, land leveling or grading between the ditches can improve the uniform distribution of water.
- Irrigation efficiencies can be reasonable (50 to 60%) where soils are underlain by impermeable layers and where diligence is practiced for reuse of runoff.
- Flow onto fields from contour ditches can be semi-automated by use of continuously moving portable dams. The ditch generally must be well sodded since flow is typically over the bank. This works well with permanent crops, such as alfalfa, clover, and pasture.

(2) Limitations

- High labor requirement until system is fully established, then labor can be low.
- Should not be used on highly erodible soils unless stabilized by permanent sod type crop. It is recommended crop establishment be done with a temporary sprinkler system.
- Open ditch maintenance is high.

(3) Planning and design considerations

The most frequently encountered problem with contour ditch irrigation is maintaining adequate water spread throughout the length of run. The more uniform the field slope, the more uniform the irrigation flow is across the irrigation set. Corrugations installed down the principal grade are often used to help maintain uniform distribution.

Contour ditch systems are generally designed from local experience. The planning technician must follow up with the irrigator to assist in making adjustments as necessary to improve distribution uniformity. Table 6–2 provides estimates of design efficiencies. Under best site and management conditions, overall application efficiencies of 35 to 60 percent are possible. Typically, efficiency is in the range of 25 to 50 percent. Collection of runoff and redistribution is necessary to obtain these levels. See table 6–3 for general guidelines for recommended maximum length of run using a unit width stream of 0.01 cubic foot per second per foot.

(4) Design procedures

Designs for contour ditch irrigation systems are difficult because the ground surface, slopes, and lengths of run vary. Only rough approximations can be made, and adjustments after initial irrigations are necessary. Basic surface irrigation system design principles and field experience have been used to develop design tables and computer programs. See section 652.0605 for design tables, procedures, and examples.

Table 6–2 Recommended design efficiencies for contour ditch irrigation systems [1]

Field slope [2] %	Design slope %	Border intake family 0.1	0.3	0.5	1.0	1.5	2.0	3.0
0.00 - 0.10	0.10	50	50	55	60	60	60	60
0.10 - 0.25	0.20	50	50	55	60	60	60	60
0.25 - 0.50	0.40	50	50	55	50	60	60	60
0.50 - 1.00	0.75	50	50	55	50	60	60	60
1.00 - 2.00	1.50	40	45	50	50	55	55	55
2.00 - 4.00	3.00	40	45	50	50	55	55	55
4.00 - 6.00	5.00	35	40	40	40	45	45	45
6.00 - 9.00	7.50	35	40	40	40	45	45	45
9.00 - 15.00	11.00	35	40	40	40	45	45	45

1/ These recommended design efficiencies are based on good maintenance and management. Land smoothing between contour ditches is assumed.

2/ With field slopes of less than 2 percent, very smooth topography, and with nearly parallel contours, an alternative system, such as graded borders, may provide better overall control of irrigation water.

Table 6–3 Contour ditch irrigation—length of run, maximum length of run, and average irrigation time (unit width stream = 0.01 cubic foot per second per foot)

Border intake family	Net irrig. appl. (in)	Approx. irrig. time (hr)	Maximum length of run (ft) 1/									
			slope groups (%)									
			1 to 2		2 to 4		4 to 8		8 to 16		16 to 32	
			MST (ft)	VST (ft)	MST (ft)	VST (ft)	MST (ft)	VST (ft)	MST (ft)	VST (ft)	MST (ft)	VST (ft)
0.1	1.0	4.9	250	500	275	300	125	200	90	150	60	100
	2.0	15.0	250	500	175	300	125	200	90	150	60	100
	3.0	31.0	250	500	175	300	125	200	90	150	60	100
	4.0	50.0	250	500	175	300	125	200	90	150	60	100
0.3	1.0	3.6	250	440	175	300	125	200	90	150	60	100
	2.0	5.1	250	500	275	300	125	200	90	150	60	100
	3.0	8.2	250	500	175	300	125	200	90	150	60	100
	4.0	12.0	250	500	175	300	125	200	90	150	60	100
0.5	1.0	2.2	250	330	275	300	125	200	90	150	60	100
	2.0	4.3	250	420	175	300	125	200	90	150	60	100
	3.0	6.6	250	490	175	300	125	200	90	150	60	100
	4.0	7.1	250	500	175	300	125	200	90	150	60	100
	5.0	9.1	250	500	275	300	125	200	90	150	60	100
	6.0	11.0	250	500	175	300	125	200	90	150	60	100
1.0	1.0	1.2	175	175	175	185	125	200	90	150	60	100
	2.0	2.1	215	215	175	225	125	200	90	150	60	100
	3.0	3.2	250	250	175	260	125	200	90	150	60	100
	4.0	4.4	2250	275	175	290	125	200	90	150	60	100
	5.0	5.7	250	305	175	300	125	200	90	150	60	100
	6.0	7.0	250	330	175	300	125	200	90	150	60	100
1.5	1.0	.08	125	125	135	135	125	140	90	150	60	100
	2.0	1.5	150	150	160	160	125	16	90	150	60	100
	3.0	2.2	175	175	175	185	125	195	90	150	60	100
	4.0	3.0	190	190	175	200	125	200	90	150	60	100
	5.0	3.8	205	205	175	215	125	200	90	150	60	100
	6.0	4.6	220	220	175	240	125	200	90	150	60	100
2.0	1.0	.07	100	100	105	105	110	110	90	120	60	100
	2.0	1.2	115	115	125	125	125	130	90	135	60	100
	3.0	107	130	130	135	135	125	145	90	150	60	100
	4.0	2.3	145	145	150	150	125	160	90	150	60	100
	5.0	2.9	155	155	165	165	125	170	90	150	60	100
	6.0	3.5	170	170	175	175	125	180	90	150	60	100
3.0	1.0	0.5	70	70	75	75	80	80	85	85	60	100
	2.0	0.8	85	85	90	90	90	90	90	100	60	100
	3.0	1.2	90	90	95	95	100	100	90	105	60	100
	4.0	106	100	100	105	105	110	110	90	115	60	100
	5.0	2.0	110	110	110	110	115	115	90	120	60	100
	6.0	2.4	115	115	120	120	125	125	90	130	60	100

1/ MST - Moderately Smooth Topography—Contours are essentially parallel and cross slope is not more than a fourth the general downslope. No rills, dikes, or furrows are present.
VST - Very Smooth Topography—Contours are very smooth and nearly parallel, and cross slope does not exceed 0.1 percent. All minor irregularities have been removed by land smoothing.

(h) Furrow erosion control

Irrigation induced furrow erosion is a major problem on highly erodible soils with slopes as flat as 1 percent. Even soils that have flatter slopes can have erosion problems. Maximum allowable furrow flow is, in most part, determined by the amount of erosion that may occur. Soils may erode if the furrow velocity exceeds about 0.5 feet per second. Figure 5–13 in NEH Part 623 (Section 15), Chapter 5, Furrow Irrigation, shows velocity and depth of flow for various stream sizes and grades in a standard shaped furrow. Recommended maximum allowable stream sizes are:

$Q = 15 / S$	erosion resistant soils
$Q = 12.5 / S$	average soils
$Q = 10 / S$	moderately erodible soils
$Q = 5 / S$	highly erodible soils (This value can range from 3 to 9, depending on erodibility of soils.)

where:
Q = gpm per furrow
S = slope in percent

A practical upper limit for inflow rate is about 50 gallons per minute, regardless of furrow slope. Streams larger than 50 gallons per minute generally require a much larger furrow cross section, or furrow ridge inundation occurs.

Sampling the amount of sediment coming off a field being planned for irrigation, or one similar to the one being planned, is the best way to determine degree of erosion. Close observations must be made along the entire furrow length to see where erosion is actually occurring and where sediment deposition is occurring. Erosion and sediment deposition throughout the length of the furrow is a dynamic process. Typically, most erosion occurs within the first few feet of furrow length or in the last few feet of the furrow. The primary cause is high velocities from head ditch outlets (gated pipe, siphon tubes, spiles, etc.) or excess dropoff at end of furrow into tailwater collection ditches.

An Imhoff cone may be used to evaluate furrow sediment discharge. Flow at any point in the furrow length can be used, but the sample is generally taken at the outflow point. A 1 liter sample is taken, placed in the Imhoff cone and allowed to settle for 30 minutes (Trout 1994). The sediment level in the cone is read directly in ml/L. Conversion from volume to weight is necessary. This conversion can be estimated at 1 gram = 1 mL, or can be determined by calibration using local soils. Furrow outflow rate throughout the irrigation, furrow length and spacing must be known to estimate sediment yield in tons per acre for that specific field condition. Many tests are required with fully controlled conditions before collected data can be accurately expanded to other conditions, such as other soils, slopes, residue amounts, and furrow flow, length, shape, and roughness.

The planning technician can suggest several alternatives to the water user for reducing furrow erosion to acceptable levels. For example, conversion to a low application rate sprinkler system may be necessary to reduce erosion to desirable levels. With highly erosive soils, furrow irrigation can be difficult to manage in a manner that allows water to be applied uniformly and efficiently and yet have minimal erosion. High levels of water management and residue intensive cultural practices are generally required when surface irrigating highly erosive soils on field slopes of more than 1 percent.

Some methods and practices that can reduce field erosion and sediment deposition in tailwater collection facilities and surface water bodies are:

Improve water application—Change inflow rate, change time of set, or use surge technique. All parameters must be evaluated so as to not increase deep percolation losses in the upper part of the field. An increase in deep percolation can mean increased potential for ground water pollution.

Modify existing system—Shorten length of run or reduce irrigation grades with corresponding changes of furrow inflow rate.

Convert to another irrigation method (or system)—Change system to a low application rate sprinkler or micro irrigation system.

Change cropping sequence or crops—Use higher residue producing crops.

Change tillage systems, reduce tillage operations, or change tillage equipment—Use reduced tillage or no-till cultural practices to maintain higher rates of residue on the soil surface.

Improve surface residue—Place straw in furrow by hand or equipment.

Install vegetative filter strips at head or lower ends of field, or both—Plantings can be permanent or temporary. These areas are typically equipment turn areas with few or no plants. A vegetative filter strip at the lower end of field helps filter out sediments as well as chemicals (fertilizers and pesticides) attached to the eroded soil particles.

Change land use—Convert to crops providing permanent cover.

Redistribute the collected sediment (this is topsoil)—Annually haul and respread the collected eroded soil as a normal farming operation. This may be needed only during the years when crops are grown without sufficient surface residue or permanent cover.

Add polycrylimide to furrow inflow water—
Recent field research by ARS has demonstrated that erosion reduction can also be realized by adding polyacrylamide (PAM), at very low concentrations, to the irrigation inflow stream (about 1 lb/acre per irrigation). PAM reduces erosion by stabilizing soil in the bottom and sides of the furrow and by flocculating suspended sediments. It is presently used in the food processing and wastewater treatment industries to flocculate suspended solids, allowing them to settle out. Application during the advance phase of the first and third to fifth irrigation is generally sufficient unless cultivation destroys the furrow seal. Whey from cheese making has also showed promise as a soil stabilizer.

One method to analyze potential furrow erosion and sediment yield and the effect of various conservation measures is to use the procedure in WNTC Engineering Tech Note W-23, *Furrow Sediment & Erosion Program, FUSED.* This procedure was developed using results from field research at the University of Wyoming and the ARS in Kimberly, ID. The process includes predicting:

- Sediment yield from the end of a field
- Amount of erosion at the upper end of the field
- Depth of soil eroded
- Years to erode a given depth of soil as a result of furrow irrigation
- Impacts of a number of applicable conservation practices

A computer program was developed in West NTC area to assist in making computations when comparing alternatives. The program user manual should be consulted for detailed guidance. An example using FUSED computer program for determining furrow erosion and sedimentation is presented in Chapter 15, Resource Planning & Evaluation Tools and Worksheets.

Caution should be used in expanding FUSED to other areas without providing local field evaluations and monitoring. USLE and RUSLE replacement program, WEPP, when completed and field tested, will contain erosion and sediment yield determination modules for various irrigation systems. WEPP should be used in place of FUSED when it becomes available.

652.0602 Sprinkle irrigation systems

(a) General

With the sprinkle irrigation method, water is applied at the point of use by a system of nozzles (impact sprinkler heads, spray nozzles, etc.) with water delivered by surface or buried pipelines. Sprinkler irrigation systems are classed by operation of the laterals. The three main types of sprinkle systems (laterals) are fixed, periodic move, and continuous/self move.

Sprinkler irrigation system examples include solid set (portable and permanent), handmove laterals, side roll (wheel-line) laterals, end tow laterals, hose fed (pull) laterals, perforated pipe laterals, high and low pressure center pivots and linear (lateral) move laterals, and stationary or traveling gun sprinklers and booms. Low Energy Precision Application (LEPA), and Low Pressure In Canopy (LPIC), systems are included with sprinkler systems as an operational modification to center pivot and linear move systems.

Pressure for sprinkler systems is generally provided by pumping, powered by electric motors and diesel, natural gas, L P gas, or gasoline engines. Where sufficient elevation drop is available, sprinkler systems can be operated using gravity to provide the necessary operating pressure.

If the system is properly designed and operated, application efficiencies of 50 to 95 percent can be obtained. The efficiency depends on type of system, cultural practices, and management. Poor management (i.e., irrigating too soon or applying too much water) is the greatest cause of reduced water application efficiency when using sprinklers. System losses are caused by:

- Direct evaporation in the air from the sprinkler spray, from the soil surface, and from plant leaves that intercept spray water.
- Wind drift (normally 5 to 10 percent depending on temperature, wind speed, and droplet size).
- Leaks and system drainage.
- Surface runoff and deep percolation resulting from, nonuniform application within the sprinkler pattern. If the system is designed to apply water at less than the maximum soil infiltration rate, no runoff losses will occur. With some systems where water is applied below or within the crop canopy, wind drift and most evaporation losses are reduced. Soil surface storage is especially important where low pressure in-canopy center pivot laterals are used. LEPA systems use complete soil, water, and plant management to prevent runoff.

The water infiltration process under sprinkler irrigation differs from that in surface irrigation. With surface methods, water is ponded on the surface. With sprinkle irrigation, water is applied so ponding does not occur or is only temporary. System application rate should be less than the maximum allowable rates shown in Chapter 2, Soils, unless soil surface storage (ponding) can be assured without appreciable translocation of applied water.

On sloping sites where the soils have a low to medium intake rate, runoff often occurs under center pivot systems, especially at the outer end of the sprinkler lateral. Developing surface storage with reservoir tillage, rough tillage, and residue management practices or temporarily increasing intake rate with ripping between plant rows helps control water translocation.

Planning and design considerations and guidelines for selection of sprinkler irrigation equipment presented later is not all inclusive. Refer to NEH, Part 623, (Section 15), Chapter 11, Sprinkle Irrigation, for further details. Operating pressures for these guidelines are grouped as follows:

Pressure	lb/in^2
Low	2 to 35
Moderate	35 to 50
Medium	50 to 75
High	75+

The range of single event application efficiency (E_a) values for various types of sprinkle systems are displayed in table 6–4. Season long irrigation application efficiencies typically are lower because of early season plant water requirements and soil intake rate changes.

Soil characteristics relating to irrigation are provided in Chapter 2, Soils. Crop characteristics relating to irrigation are provided in Chapter 3, Crops, and irrigation water requirements are provided in Chapter 4, Water Requirements.

The required capacity of a sprinkle irrigation system depends on the size of the area irrigated, gross depth of water to be applied at each irrigation, and the operating time allowed to apply the water. See NEH, Part 623, Chapter 2, Irrigation Water Requirements, for further details regarding crop water needs. The required capacity of a sprinkle system can be computed by:

$$Q = \frac{453\,A\,d}{f\,T} \qquad \text{or} \qquad Q = \frac{453\,A\,d'}{T}$$

where:

Q = system capacity (gpm)
A = area irrigated (acres)
d = gross depth of application (inches)
f = time allowed for completion of one irrigation (days)
T = actual operating time per day (hours per day) to cover entire area
d′ = gross daily water use rate (inches per day)—may be peak or average, depending on need and risks to be taken.

Note: This equation represents the basic irrigation equation QT = DA with conversion factors for sprinkler irrigation design. Typically, tables readily available by NRCS and manufacturers pertaining to sprinkler heads, pipe friction losses, and pump curves are in units of gallons per minute (gpm) rather than cubic feet per second, cubic meters per second, or liters per minute.

Table 6–4 Application efficiencies for various sprinkler systems

Type	E_a (%)
Periodic move lateral	60 – 75
Periodic move gun type or boom sprinklers	50 – 60
Fixed laterals (solid set)	60 – 75
Traveling sprinklers (gun type or boom)	55 – 65
Center pivot - standard	75 – 85
Linear (lateral) move	80 – 87
LEPA - center pivot and linear move	90 – 95

(b) Periodic move sprinkler irrigation systems

A periodic move sprinkler irrigation system is set in a fixed location for a specified length of time to apply a required depth of water. The length of time in a position is called the length of set or irrigation set time. The lateral or sprinkler is then moved to the next set position. Application efficiencies can range from 50 to 75 percent for the low quarter area of the field (E_q). The low quarter area definition commonly applies to all periodic move or set type sprinkler systems.

(1) Periodic move systems

(i) Handmove laterals—This system is composed of portable pipelines with risers and sprinkler heads. Portable or buried mainline pipe with uniformly spaced valve outlets provides a water supply. Portable aluminum, or sometimes plastic, lateral pipe has quick couplers. Risers and sprinkler heads are either center-mounted or end-mounted. Lateral sections are typically 20, 30, or 40 feet long. When the lateral has completed the last set location in the field, it must be dismantled and moved back across the field to the start position unless multiple laterals are used and the finish location is adjacent to the start location of the next set. Application efficiencies can be 60 to 75 percent with proper management.

A handmove system has a low initial cost, but requires high operating labor. It is difficult to use in tall crops, such as corn or mature vineyards. Riser height must be based on maximum height of the crop to be grown. For hydraulic reasons minimum height is generally 6 inches. Risers over 4 feet in height must be anchored and stabilized. Handmove systems are sometimes used to establish a crop that will later be irrigated by a surface system. Leaching salts and other toxic ions from soils is sometimes accomplished using handmove sprinklers. Handmove sprinklers are easily adapted to odd shaped fields. Because 3-inch diameter laterals are easier to pick up by hand and carry to the next set, they are much preferred over those that are 4 inches in diameter. However, long laterals should be 4 inches in diameter. Because of excessive bending while being carried, 40 foot lengths of 2-inch diameter pipe are unsuitable.

(ii) Side (wheel) roll laterals—A side (wheel) roll system is similar to a handmove system except that wheels are mounted on the lateral. The lateral pipe serves as an axle to assist in moving the system sideways by rotation to the next set. The sections of the lateral pipe are semi-permanently bolted together. Each pipe section is supported by a large diameter (at least 3 ft) wheel generally located at the center, but can be at the end. The lateral pipe itself forms the axle for the wheels. The lateral is moved mechanically by a power unit (air-cooled gas engine) generally mounted at the center of the line. With proper management, application efficiencies can be 60 to 75 percent.

The side roll system can be used only on low growing crops, such as grass pasture, grain, grain sorghum, alfalfa, sugar beets, potatoes, and vegetables. The system is best adapted to rectangular fields on relatively uniform topography. A flexible hose or telescoping section of pipe is required at the beginning of each lateral to connect onto mainline outlet valves.

Wheel diameters should be selected so that the lateral clears the crop. Specified lateral move distance is equal to the distance moved by a whole number of rotations of the line. Commonly used nominal wheel diameters are about 5, 6, and 7 feet. Wheels as large as 10-foot diameter are sometimes used to clean taller crops or to allow wheel lines to be moved across furrows and ridges.

Self-righting or vertical self-aligning sprinkler heads are used because the sprinkler head is always upright, even with partial rotations. Without the self aligning heads, extra care must be taken so that the pipe rotation is fully complete for the full length of the lateral and all sprinkler heads are upright. The ends of the lateral usually trail a little and must be moved by hand for proper alignment, or the lateral can be moved just past the set position and then backed up to align the ends properly. Poor distribution uniformity results if the sprinkler heads are not upright. Undulating topography usually requires alignment by hand for best uniformity.

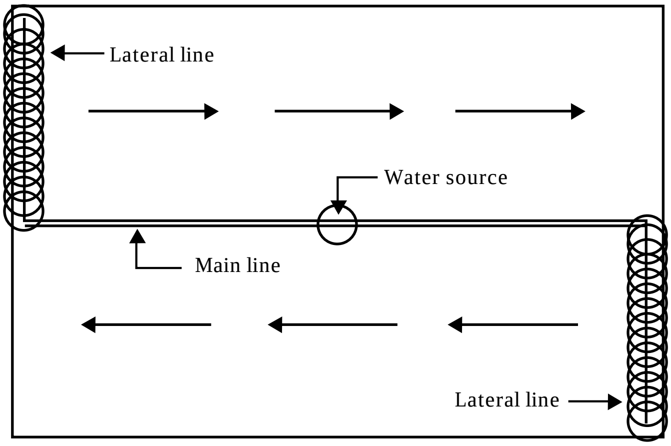
Side roll lateral pipe diameters of 4 or 5 inches are most common. Common sprinkler head spacing is 30 or 40 feet. Laterals can be up to 1,600 feet long with one power unit. Lateral lengths of 1,320 feet are generally considered maximum for rough, steep, or undulating topography. Figure 6–7 displays a typical side roll or handmove system operation layout.

Quick-drain valves are installed at several locations on each lateral to assist line drainage before it is moved. The lateral moves much easier when it is empty. Drain valves are a factor in the minimum operating pressure that must be used on the lateral. Typically drains will not close and seal properly below about 24 pounds per square inch. Drain valves should be well maintained to provide proper closing upon filling the lateral line to start the next irrigation set.

Empty laterals must be anchored to prevent movement by wind. They roll very easily and should be properly restrained, especially during the nonirrigation season when the irrigator spends little time in the field.

A variation to the side roll lateral (called side move) is the addition of small diameter trail lines at each sprinkler head location. These trail lines can have three, four, or five sprinkler heads, and the complete unit can be an equivalent of two or three typical laterals. With this modification, the lateral pipe cannot serve as the axle when being moved because trail lines are attached directly to the lateral pipe. A separate drive shaft and the main sprinkler lateral are supported by an A-frame at each wheel location. The A-frame is supported by two wheels.

Figure 6–7 Side roll or handmove sprinkler system layout



This variation requires dismantling of the trail lines when the lateral has reached the end set, where trail lines are hauled back to the start location. The main sprinkler lateral is typically moved back to the start location by a centrally located power unit, usually an air-cooled gas engine.

(iii) End-tow laterals—The end-tow lateral system is similar to a hand move system except that it consists of rigidly coupled lateral pipe and is mounted on skid plates or dolly wheels. The mainline is buried across the middle of the field. Laterals are towed lengthwise across the mainline from one side to the other with a tractor. Both ends of the lateral can be connected to the mainline via a flexible hose. After draining the pipe through quick-drain valves, a small tractor can easily tow a quarter-mile-long line to its new set.

Two support or carriage types are available. One is a skid plate attached to each coupler to slightly raise the lateral pipe off the ground, protect the drain valve, and provide a wear surface when towing the pipe. Outriggers are placed every 200 to 300 feet to prevent overturning. The other carriage type uses small metal wheels located midway between couplers to allow easy towing. Guide rollers are used near the mainline to position the lateral at the next set. Typically lateral positions are offset a half of the total move. Application efficiencies can be 60 to 75 percent with proper management.

This system is best suited to grass pasture, but can be used in row crops if unplanted tow paths are maintained. It requires a fairly large area adjacent to the mainline to allow positioning of the lateral to the next set on the opposite side of the mainline. When used with row crops, this area can be planted to grass or alfalfa. The advantage of this system is its relatively low cost and minimum labor requirement.

(iv) Hose fed (pull) laterals—A variation to end-tow laterals is the hose fed system. A few (typically one to five) low capacity sprinkler heads are mounted on small diameter flexible plastic or rubber hoses that are attached to outlet valves. The hoses with equally spaced sprinklers are pulled by hand to the next adjacent set. To utilize small, light weight flexible hose that can be easily moved by hand, submains are used. The number of sprinkler heads, thus the length of laterals, is limited by both high friction loss in the small diameter hose and the ease of moving. This system is excellent for orchards and irregular shaped fields where the number of sprinklers per hose can vary in proportion to the field or set width to be covered. With proper management, application efficiencies can be 50 to 65 percent.

(v) Gun type sprinkler—Large, periodic move, gun type sprinklers are operated and moved as a large single impact type sprinkler head. Sprinkler discharge flows can range from 50 to more than 1,000 gallons per minute. Nozzle diameters can vary from 1/2 to 1 3/4 inches, and operating pressures from 60 to more than 120 pounds per square inch. The sprinkler is moved from one set to the next set either by hand or using a small tractor, depending on their size and whether they are towable. Generally only one sprinkler is operated per lateral. Laterals are generally aluminum pipe with quick-coupled joints.

When irrigating, the sprinkler is allowed to remain at one location (set) until the desired amount of water is applied. Application rates can be very high, and uniformity of application can be adversely effected with wind greater than 4 miles per hour. Droplet size will be large beyond 50 feet from the sprinkler, thus soil puddling can occur and sensitive crops can be damaged. With proper management, application efficiencies can be 50 to 60 percent.

(vi) Boom sprinkler—Periodic move boom systems are operated and moved with a tractor similar to large gun sprinklers. The boom generally contains several closely spaced impact sprinklers or spray heads. It rotates around a central swivel joint where water is introduced. Power for the rotation comes from back pressure caused by directional sprinkler nozzles. The supply line is generally portable aluminum with quick-coupled joints. When irrigating, the boom is allowed to remain at one location (set) until the desired amount of water is applied.

Boom sprinkle systems are not suitable for use in windy areas. Wind adversely affects uniformity of application and rotational operation. High winds can overturn the entire boom. With proper management, application efficiencies can be 50 to 60 percent.

(vii) Perforated pipe—Perforated pipe systems spray water from 1/16-inch diameter or smaller holes drilled at uniform distances along the top and sides of a lateral pipe. The holes are sized and spaced to apply water uniformly along the length of the lateral. Common operating pressures are 5 to 20 pounds per square inch. Application rates close to the lateral are generally quite high. Spacing between lateral sets must be quite close to obtain an acceptable uniformity of application. Either plastic or aluminum laterals with quick-coupled joints are used. Water used must be free of debris, otherwise hole plugging is a problem. With proper management, application efficiencies can be around 50 percent.

(2) Planning and design considerations

(i) Sprinkler heads—Rotating, impact type sprinkler heads operating at intermediate pressure (30 to 60 lb/in^2) are commonly used on periodic move lateral type systems. Rotating impact sprinkler heads come with many variations including full circle, part circle, low and standard trajectory height, with and without straightening vanes, and single or double nozzle. The second nozzle on a double nozzle head is typically a 3/32- or 1/8-inch diameter orifice. It is used as a fill-in to improve pattern uniformity.

Flow control valves at the base of each sprinkler head or flow control nozzles may be required where the terrain undulates or has significant changes in elevation. Flow control nozzles require about 2 to 4 pounds per square inch. Impact type sprinkler heads can be operated at 25 to 35 pounds per square inch to reduce energy. Some systems operate on gravity pressure.

(ii) Laterals—Laterals are generally laid out perpendicular to the slope. To obtain near-uniform application of water throughout the length of lateral, pipe diameter and length should result in discharge at the sprinkler nozzle within plus or minus 10 percent of design. (A maximum nozzle pressure difference of 20 percent provides a discharge not varying more than 10 percent from each nozzle.) To create less confusion and to facilitate dismantling, moving, and stacking, the same sprinkler head, nozzle size, and diameter of lateral are recommended throughout the length of hand move laterals. Convenient set times are 23.5, 11.5, or 7.5 hours, thus allowing a half hour for draining and moving laterals, with one, two, or three moves per day. Moving the lateral three times a day is not popular because one move always comes in the dark at a inconvenient time and with increased labor cost.

(iii) Lateral set sequencing—Lateral sets can be sequenced in several ways. Using a typical 40 by 50 foot spacing for a periodic move lateral system, the following methods can be used to move laterals across a field.

Move at 50-foot sets across the field. Portable laterals must be dismantled and hauled back to the first set position. Side roll laterals must be rolled all the way back to the first or initial set position. The irrigator may choose to apply half the irrigation application in each direction. However, this requires twice the number of moves. Distribution uniformity is reasonable under conditions where moderate pressure is used and wind is not a serious problem.

Move at 100-foot sets across the field. Then reverse direction and move back at alternating 100 foot sets. This allows convenient operation of the system without having to dismantle and haul back or move the lateral to the initial or start position. Distribution uniformity depends on wind conditions. Lateral pipes are hand carried twice as far as in the first method, but the lateral does not need to be dismantled and hauled back.

Use 25-foot offset pipe when moving across the field the second time and each alternating set thereafter, with both the 50-foot and 100-foot set methods. This procedure improves overall distribution uniformity especially in windy areas. Existing 50-foot systems can be easily converted by adding a 20- to 30-foot swing or offset line. (Slight realignment of the lateral is needed to evenly divide the set.)

With any set sequence, alternating day-night set with each rotation across the field is recommended. Crop evapotranspiration or winds generally are different during daytime and nighttime hours causing varying losses. Nighttime application is generally more efficient with better distribution uniformity. As much as 10 percent more net application is accomplished with night time sets. Sometimes 11-hour night sets and 13-hour day sets are used to overcome the difference.

(3) Application efficiencies

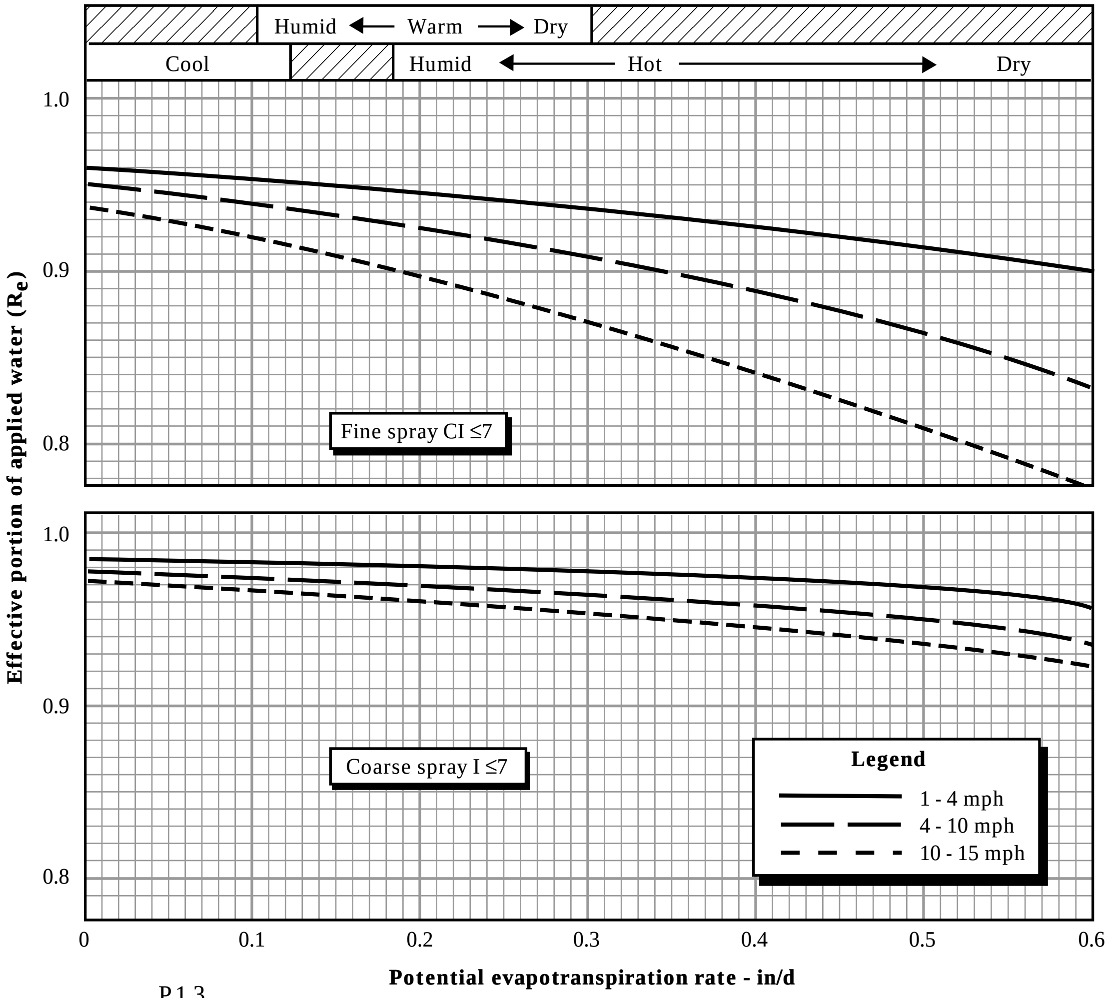
Both Distribution Uniformity (DU), and Christiansen Uniformity (CU) coefficients are used to determine the application efficiency (E_a) of the low quarter (E_q or AELQ) or of the low half (E_h or AELH). This then becomes the design application efficiency.

$$E_q = DU \times R_e \quad \text{and} \quad E_h = CU \times R_e$$

where:
R_e = effective portion of water applied

CU estimates can be obtained from NEH, part 623 (section 15), chapter 11, tables 11-9 to 11-12. R_e estimates are obtained using figure 6–8.

Figure 6–8 Effective portion of applied water—R_e



$$CI = \frac{P^{1.3}}{B}$$

Where:
CI = spray coarseness index
P = nozzle operating pressure (psi)
B = nozzle size (64ths of an inch)

If the value of CI is less than 7, the spray is coarse. If it is more than 17, the spray is fine. When the value of CI falls between 7 and 17, the R_e value can be interpolated.

***(i) Moderate and low operating pressures*—**Impact type sprinkler head operating pressures below 35 pounds per square inch require close lateral and sprinkler head spacing. Low pressure sprinkler heads are available to use with low pressure operation, 25 to 35 pounds per square inch. Spacing of heads on laterals and distance moved (spacing between laterals) must be designed accordingly to provide acceptable uniformity. About 25 pounds per square inch is the lowest operating pressure recommended for impact type sprinkler heads. Standard lateral drain valves may not close properly when operating pressures are below 24 pounds per square inch. Sprinkler head spacing and lateral move distances of 20 by 20 feet, 20 by 30 feet, 30 by 30 feet, and 30 by 40 feet are common with low pressure operation.

***(ii) Flow regulation devices*—**Flow regulation devices or pressure regulators are either inserted near the base of the sprinkler, or they are an integral part of the sprinkler nozzle. The friction loss through the regulator, typically 2 to 4 pounds per square inch, must be included in calculations for required mainline operating pressure, especially when using low operating pressures. For example, if a valve was selected to maintain about 30 pounds per square inch at the sprinkler, a pressure loss of about 4 pounds per square inch can be expected across the regulator and must be accounted for.

***(iii) Preliminary estimate of sprinkler spacing and sprinkler sizes*—**NEH, part 623 (section 15) chapter 11, tables 11–9 to 11–12 can be used to make a preliminary estimate of sprinkler spacing, nozzle size, and operating pressure. Many design slide rules and computer programs are available from sprinkler equipment manufacturers. The slide rules are convenient for developing preliminary design trials and for estimating purposes. A preliminary estimate of overall irrigation application efficiency is required. Experience in an area and personally doing several designs and field evaluations help provide confidence in planning and designing.

(4) Design procedures

A step-by-step procedure for planning and designing a sprinkler irrigation system includes:

Step 1—Identify resource concerns and problems. Determine objective(s) and purpose of new or revised irrigation system. Include soil, water, air, plant, and animal resources, and human considerations.

Step 2—Inventory resources for field or farm. Include area irrigated, soil(s), topography, water source, and when available, water quantity and quality, power type and location, crops, irrigator's desire for a type of sprinkler system and timeframe for moving laterals, labor availability, availability of sprinkler irrigation equipment dealers, and water management skill and desire of the irrigation decisionmaker.

Step 3—Determine soil characteristics and limitations. Include AWC, maximum allowable application rate, usable rooting depth, acidity, salinity, and water table. Typical (actual) crop rooting depth needs to be identified for specific fields and soils. In most soils, actual depth (and pattern) is less than usable rooting depth because of farm management decisions (i.e., timing of field operations) and type of field equipment used. A field investigation is strongly recommended in addition to data in the local NRCS FOTG. If a field contains more than one soil, the most restrictive soil must be determined. Crops use essentially the same amount of water whether growing in sand or clay soil. Thus, the system should be managed to meet the needs of the more restrictive soil.

Step 4—Determine net irrigation water requirements for crops to be grown. Use season, month, and peak or average daily use rate, accounting for expected rainfall and acceptable risks.

Step 5—Determine irrigation frequency, net application, gross application (based on estimated application efficiency), and minimum system capacity requirements.

Step 6—Determine alternative irrigation systems suitable to the site. Include the sprinkler system desired by the user. Evaluate alternative irrigation systems and their multiresource impacts on the environment (soil, water, air, plant, animal, and human considerations) with user.

Step 7—Provide preliminary sprinkler head design. Include spacing, discharge, operating pressure, wetted diameter, head type, nozzle size(s), average application rate, and performance characteristics.

Step 8—Determine number of laterals needed for selected time of set, set spacing, moves per day, and frequency of irrigation in days.

Step 9—Evaluate design. Does it meet the objective and purpose(s) identified in step 1?

Step 10—Make adjustments as needed. This process may need to be done more than once so the system fits the field, soils, crops, water supply, environmental concerns, and the desires of the irrigation decisionmaker.

Step 11—Finalize sprinkler irrigation system design, layout, and management skills required by the irrigation decisionmaker.

Step 12—Determine lateral size(s) based on number of heads, flow rate, pipeline length, and allowable pressure loss differential between first and last sprinkler head. Determine if pressure or flow regulators are needed. Determine minimum operating pressure required in mainline(s) at various critical locations on the terrain. Several trial lateral locations may need to be evaluated to determine the range of friction loss and consequent pressure required at various locations along the mainline.

Step 13—Determine mainline sizes required to meet pressure and flow requirements according to number of operating laterals. This includes diameter, pipe material, mainline location, and the location and type of valves and fittings. It involves hydraulic calculations, basic cost-benefit relationships, and potential pressure surge evaluations for pipe sizes and velocities selected. Mainline operating pressure measured at the discharge side of each lateral outlet valve should be within 10 percent of the design lateral operating pressure. Where chemigation is anticipated, less operating pressure difference is desirable. A graphic solution can be helpful when sizing main supply pipelines. The ground line and pipe hydraulic grade line (HGL) along the mainline can be plotted for easy identification of critical pressure locations. The distance between the ground line and HGL will be the operating pressure at that main line location.

Step 14—Determine maximum and minimum Total Dynamic Head (TDH) required for critical lateral location conditions. Determine total accumulated friction loss in mainline, elevation rise (drop) from pump to extreme point in the fields, water surface to ground surface (lift) at pump, column loss with vertical turbine pumps, and miscellaneous losses (fittings, valves, elbows) at the pump and throughout the system. It is wrong to assume miscellaneous losses are minor and to gloss over them. Type and size of valves, radii of elbows, and sharpness of fittings are important. Check them out and know how they affect system performance. See section 652.0605 for nomographs and tables used to estimate head losses.

Step 15—Determine maximum and minimum pumping plant capacity using required flow rate and TDH. Estimate brake horsepower for the motor or engine to be used.

Step 16—Preselect several alternative pumps available from various dealers in the area. Use pump performance curves prepared for each make and model of pump. Every pump has a different set of performance (characteristic) curves relating to operating head (pressure) output and discharge capacity. Select pump(s) and power unit(s) for maximum operating efficiency within the full range of expected operating conditions. Multiple pumps may be desirable to efficiently meet both minimum and maximum conditions. Pump and drive unit alternatives are recommended as a reference for determining availability. Only pump capacity and TDH requirements are recommended to be provided to the user. Never select a pump based on horsepower alone. Let a pump dealer select the appropriate motor or engine and pump to fit the conditions. Availability of a pump dealer for providing maintenance and repair should be considered by the operator. Buying a used pump without first checking pump characteristic curves for that specific pump is seldom satisfactory. A pump needs to match the required capacity and TDH for efficient and economic performance. An inefficient operating pump can use needless excess energy.

Step 17—Prepare final layout and operation, maintenance, and irrigation water management plans. Include method(s) of determining when and how much to irrigate (irrigation scheduling). Provide recommendations and plans for at least one water measuring device to be installed in the system for water management purposes.

Planning steps may be substantially abbreviated when the planning technician provides only basic resource information and limitations. The design of the sprinkler system and components is done by an irrigation system design consultant or equipment dealer. Regardless of who does the design, the processes listed in steps 1 through 17 should be followed to provide an adequate system suitable to the site.

Design procedures and examples are provided in section 652.0605 and in more detail in NEH, Part 623, (Section 15), Chapter 11, Sprinkle Irrigation. Manufacturer literature is readily available and most useful in selection of sprinkler head models, nozzle sizes, and discharge at various pressures.

Example 6–1 Typical field data for a side roll (wheel line) lateral system

Known data from Field Office Technical Guide:

Crop:	Alfalfa	Peak ETc	= .30 in/day, MAD = 50%
Soil:	Glenberg loam	AWC for 5 ft	= low 6.9 in, mid 7.9 in, high 8.9 in
		AWC for 4 ft	= low 5.7 in, mid 6.5 in, high 7.3 in
		AWC for 3 ft	= low 4.5 in, mid 5.2 in, high 5.8 in

Soil sprinkler intake rate: 0.40 in/hr (max. sprinkler application rate)

where:
ET_c = crop evapotranspiration
MAD = management allowable depletion (deficient)
AWC = available water capacity of soil

Field: 80 acres, 1,320 x 2,640 feet, rectangular

Water source: Well at midway point of the long way of field on one edge (see sketch on worksheet)
water depth *while pumping* = 100 ft
measured maximum flow = 1,000 gpm

Power: Power available at well is 3-phase, 440-volt AC electric current

Topography: Maximum difference in elevation (all slopes are uniform):
between field midway point and uphill end of most faraway lateral = 25 ft
to downhill end of field from midway point = 20 ft
elevation difference (uphill) from well across midway point of field = 12 ft

Landowner wants to complete irrigation in 6 days or less. Convenient set times are 8, 12, or 24 hours (including a half hour for draining and changing laterals for each move). Prefers side roll laterals.

Example 6–1 Typical field data for a side roll (wheel line) lateral system—Continued

Find:

- Net and gross application in inches and frequency in days
- Select sprinkler head make, model, sprinkler spacing along lateral, discharge, operating pressure, application rate, and if flow or pressure regulator are required.
- Distance lateral to be moved between irrigation each set (spacing of valve outlets), layout, length(s), and number of laterals required.
- Set times and total time to irrigate entire field.
- Flow rate per lateral, lateral material, diameter, and friction loss. Check sum of lateral(s) flow rate(s) against minimum capacity requirements with:

$$Q = \frac{453\ A\ d}{f\ T}$$

where:
Q = flow in gpm
A = area in acres
d = gross depth of application in inches
f = time allowed (frequency) for completion of one irrigation in days
T = actual operating time in hr/d

- Pressure required in mainline for worst case lateral location.
- Mainline—material, diameters, friction losses, including valves and fittings.
- Water measuring device.
- Total mainline flow requirements at pump, pump capacity.
- TDH, including lift from water level to pump.
- Pump and motor/engine size selection.

Computations:

Exhibit 6–1, Sprinkler irrigation system planning/design worksheet, is used to determine minimum irrigation requirements based on soils, crops, and system design requirements. See chapter 15 for the master blank worksheet used in this example.

Exhibit 6–1 Sprinkler irrigation system planning/design worksheet

U.S. Department of Agriculture
Natural Resources Conservation Service

Page 1 of 5

Sprinkler Irrigation System Planning/Design Worksheet

NAME ____________ DATE ____________ PREPARED BY ____________

DISTRICT ____________ COUNTY ____________ ENGR JOB CLASS ____________

Inventory

Water source ____________ Amount available ____________ ft^3/sec ____________ gpm ____________ acre-ft Seasonal variation ____________

Power source: Electric ____________ volts, ____________ phase; Internal combustion engine ____________ fuel type; Other ____________

Soils Data

Design Soil Series	Available water capacity, AWC (in/ft depth)					Depth to [1]		Sprinkler intake rate (in/hr)
	0-1	1-2	2-3	3-4	4-5	Inhibiting layer (ft)	Water table (ft)	

[1] Actual observed depth in the field.

Crop Evapotranspiration (Monthly)

Crops	Acres	Month		Month		Month	
		Depth (in)	Volume (ac-in)	Depth (in)	Volume (ac-in)	Depth (in)	Volume (ac-in)
Totals (1)		(2)		(3)		(4)	

Crop Weighted Evaportranspiration (Monthly) (Note: Maximum Monthly Total ET is greatest of nos. 2, 3, or 4 above)

$$\text{ET, depth} = \frac{\text{Maximum Total Monthly ET, ac-in/mo}}{\text{Total Acres, A (1)}} = \_\_\_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_\_\_ \text{ in /mo}$$

Irrigation Requirements

Crops	Root zone depth [2] (ft)	Total AWC (in)	Management allowed depletion (%)	Max Net replacement (in)	Peak daily ET (in)	Max freq @ peak E T @ max net (days)

[2] Use weighted peak monthly ET and net irrigation to determine weighted peak daily E T.

Exhibit 6–1 Sprinkler irrigation system planning/design worksheet—Continued

U.S. Department of Agriculture
Natural Resources Conservation Service

Page 2 of 5

Sprinkler Irrigation System Planning/Design Worksheet—*Continued*

NAME ______________________ DATE ______________ PREPARED BY ______________________

Design Data — (Based on weighted crop ET, ____________ % irrigation efficiency)

	Application		Weighted [2] peak daily crop ET (in)	Frequency, F (days)	System requirements	
	Net, D (in)	Gross F_g (in)			Total gpm, Q	gpm/ac

[2] Use weighted peak monthly ET and net irrigation to determine weighted peak daily E T.

Q = system requirements–gpm
H = Total operating hours/day
(suggest using 23 hours for one move per day)
(suggest using 22 hours for two moves per day)

$$Q = \frac{453\ A\ D}{F\ H\ \ Eff/100} = \_\_\_\_\_\_\_\_\_\_ \text{ gpm} = \_\_\_\_\_\_\_\_\_\_ \text{ gpm}$$

Sprinkler head spacing, (S_L) ____________ ft, Lateral spacing on mainline (S_M) ______________ ft, Minimum Required wetted diameter = ___________ft

Sprinkler head: make ___________; model ___________; nozzle size _________; lb/in^2 _________ gpm _________; wetted dia ______________ ft

Application rate ________ in/hr, Application time _________ hr/set. Net application = (_______ in/hr) (________ eff) (________ hr/set) = _________ in

Maximum irrigation cycle = Net applcation _________ in/peak ET in/d = _________ days

Minimum number of laterals = number of lateral sites _________ / (irrigation frequency, ________ days) (moves/day, ___________)

Designed laterals: Number ______________, Diameter ___________ in, Type _____________ , Moves/day ___________

Total number of sprinkler heads = (number of laterals) (number of heads/lateral) = ___________

System capacity = (Total number of sprinkler heads _________) (gpm/head ____________) = ____________ gpm

Lateral design

Allowable pressure difference along lateral = 0.2 (sprinkler head operating pressure in lb/in^2) = ________________ lb/in^2

Actual head loss (worst condition) ___________ lb/in^2

Pressure required at mainline: P = (sprinkler head lb/in^2 _________) + (0.75) (Lateral friction lb/in^2 ________) +/- (ft elev) / (2) (2.31) = ________ lb/in^2

(plus for uphill flow in lateral, minus for downhill flow). Use sprinkler head lb/in^2 only if elevation difference along lateral is = or > 0.75 (lateral friction loss lb/in^2) (2.31). Under this condition, flow regulation may be required at some sprinkler heads to maintain proper sprinkler head operating near the mainline.

Exhibit 6–1 Sprinkler irrigation system planning/design worksheet—Continued

U.S. Department of Agriculture
Natural Resources Conservation Service

Page 3 of 5

Sprinkler Irrigation System Planning/Design Worksheet—*Continued*

NAME ______________________ DATE ______________ PREPARED BY ______________________

Mainline Design

Mainline material ________________ (IPS, PIP, SDR, CLASS) lb/in^2 rating ______________, other description, ____________

Friction factor used ________. Formula (check one) ☐ Hazen-Williams ☐ Manning's ☐ Darcy-Weibach ☐ Other (name) ______________

Station		Diameter pipe (in)	Flow (gpm)	Velocity (fps)	Distance (ft)	Friction loss (ft/100 ft)	Friction loss this section (ft)	Accumulated friction loss (ft)	Remarks
From	To								

NOTE: desirable velocities–5 ft/sec or less in mainlines, 7 ft/sec or less in sprinkler laterals.

Determination of Total Dynamic Head (TDH)

Pressure required at main __________ lb/in^2 ____________ft

Friction loss in main __________ lb/in^2 ____________ft

Elevation raise/fall in main __________ lb/in^2 ____________ft (2.31 feet = 1 psi pressure)

Lift (water surface to pump) __________ lb/in^2 ____________ft

Column friction loss __________ lb/in^2 ____________ft

Miscellaneous loss __________ lb/in^2 ____________ft

Total (TDH) __________ lb/in^2 ____________ft (NOTE; TDH must be in feet for horsepower equation)

Approximate brake horsepower = $\frac{\text{TDH (ft) X Q (gpm)}}{\text{3960 X Eff / 100}} = \frac{\text{\_\_\_\_\_\_\_\_ ft X \_\_\_\_\_\_\_\_ gpm}}{\text{3960 X \_\_\_\_\_\_\_\_ \% / 100}}$ = __________ HP

Mean sea level elevation of pump ____________ ft (NOTE: check required versus available NPSL for centrifugal pumps)

Pump curve data attached yes ☐ no ☐, If not, pumping plant efficiency assumed = ________% (recommended using 65-75%)

Bill of materials attached yes ☐ no ☐

Exhibit 6–1 Sprinkler irrigation system planning/design worksheet—Continued

U.S. Department of Agriculture
Natural Resources Conservation Service

Page 4 of 5

Sprinkler Irrigation System Planning/Design Worksheet—*Continued*

NAME ____________________ DATE ______________ PREPARED BY ____________________

Other Design Considerations

Item	Evaluation performed	NOT needed	Location	Size
Measuring device				
Expansion couplers				
Reducers				
Enlargers (expanders)				
Manifolds				
Bends & elbows				
Tees				
Valved outlets				
Surge facilities (valves, chambers)				
Control valves				
Check non-return flow valves				
Pressure relief valves				
Air-vacuum valves				
Drain facilities				
Thrust blocks				
Anchors				
Pipe supports				
Other				

Remarks ____

Special drawing(s) attached ______________________________

Irrigation system design by ______________________ Date ______________

Reviewed and approved by ______________________ Date ______________

Exhibit 6–1 Sprinkler irrigation system planning/design worksheet—Continued

U.S. Department of Agriculture Page 5 of 5
Natural Resources Conservation Service

Sprinkler Irrigation System Planning/Design Worksheet—*Continued*

NAME ____________________ DATE ____________ PREPARED BY ____________________

Irrigation System Location and Layout Map

SHOW:
- ☐ Area irrigated with sprinklers
- ☐ Direction of prevailing wind
- ☐ Elevations, contours
- ☐ High and low points
- ☐ Water source and pump location
- ☐ Mainline and submain locations
- ☐ Layout: lateral(s), travelers, guns
- ☐ Direction of move
- ☐ North arrow

Scale	Community	Section	Township	Range

(c) Fixed-solid set sprinkler irrigation systems

A fixed or solid set sprinkler irrigation system has enough pipe and sprinkler heads that none of the laterals need to be moved to complete an irrigation once in place. Laterals can be either permanently buried or portable pipe laid on the ground surface. To irrigate the field, one or more blocks (sections) of sprinklers are cycled on and off with a control valve at the mainline. Opening and closing of valves can be manual, programmed electronically, or timer clock controlled. A solid set sprinkler system can be easily automated. Application efficiencies can be 60 to 85 percent depending on design and management.

In addition to applying irrigation water, these systems are used to apply water for environmental control, such as frost protection, crop cooling, humidity control, bud delay, crop quality improvement, dust control, and chemical application. See NEH, Part 623, Chapter 2, Irrigation Water Requirements, and section 652.0605, State supplement, for detailed discussion of auxiliary water use.

(1) Planning and design considerations

Solid set portable laterals—Solid set portable lateral systems are generally used for high value crops, such as nurseries, vegetables, or turf production, where the system can be moved from the field before harvest. However, they also can be used with permanent crops, such as orchards and berries, where the portable laterals can be left in the field. This type of system is sometimes used to germinate crops, such as lettuce, which will later be furrow irrigated.

Advantages:

- Reduced labor requirements because the pipe does not need to be moved while in the field.
- Allows light applications at frequent intervals.

Disadvantages:

- High cost of needing sufficient lateral pipe and sprinklers to cover the entire field.
- Can cause inconvenience for cultivation or other cultural operations.
- Tall sprinkler risers need support, protection, or both.

With portable mainline(s), control valves are typically operated manually. Renting a portable solid set system for limited use (crop establishment, crop cooling, specialty crops) can be more economical than ownership.

Solid set permanent laterals**—**This sprinkler irrigation system is similar to the portable system except both mainline(s) and laterals are generally buried below the depth of normal field operations. Sprinkler lateral flow can be sequenced manually or automatically by various timer activated electric solenoid valves. With annual crops, the risers are installed outside of any tillage operations. This system is most adapted to permanent crops, such as orchards, grapes, cranberries, cane berries, turf for landscaping, and golf courses. Solid set systems can be used on annual crops, alfalfa, or pasture. However, caution must be exercised during tillage or harvest operations to prevent damage to risers and sprinkler heads. Risers must also be protected from livestock.

(2) Design procedures

Design of solid set systems is similar to periodic move systems. The only difference is that each lateral is individually designed. Sizes can be effectively reduced toward the end of the lateral as flow decreases. Blocks of laterals are then tied together using submains to create operating blocks or units and minimize the number of control valves. Individual sprinkler heads and spacing are designed to fit soil, crop, desired application rates and amounts, local wind conditions, and management available. Figure 6–9 displays a solid set system layout.

With orchards and vineyards, tall risers can be used to provide overhead irrigation. Quick couplings are available for lowering sprinkler heads for maintenance and replacement. Minimum distribution uniformity standards at ground level typically cannot be met when sprinkle irrigating fruit and nut orchards, citrus groves, banana plantations, vineyards, cane berries, and tall bush berries from either overhead or ground level located sprinkler heads. However, minimum distribution uniformity standards still apply for design and operation purposes. Lateral movement of soil water is desirable and necessary in some soils to prevent dry spots in root development areas. In arid and semiarid areas, development of the support root system for trees and vines will only be in areas of adequate soil moisture. Overhead systems are preferred for climate control systems, although recent research has shown some degree of protection can be obtained from undertree sprinklers.

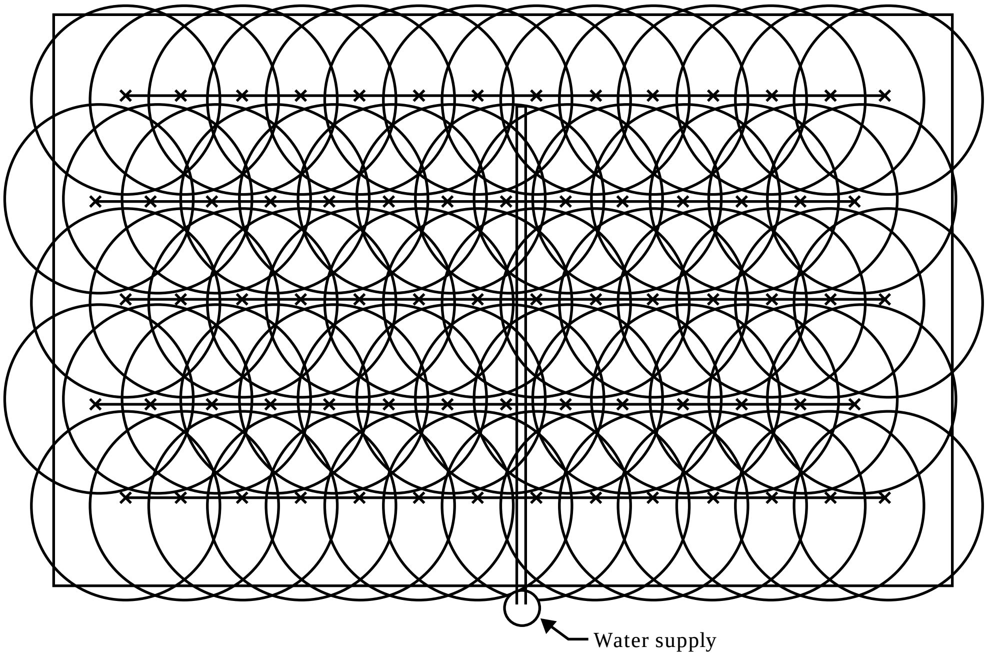
A diamond or triangular pattern for sprinkler head layout is recommended for solid set systems, thereby improving application uniformity. Adequate (typically 50%) overlapping patterns from adjacent sprinkler nozzles are essential for temperature modification systems and those used for shallow rooted annual crops regardless of sprinkler head layout. Deep rooted perennial crops like trees, blueberries, and vines tolerate less application uniformity.

(d) Continuous (self) move sprinkler irrigation systems

(1) Center pivot sprinkler irrigation system

A center pivot sprinkler irrigation system consists of a continuously moving, horizontal rotating single lateral supported by towers and anchored at a fixed pivot point at the center of the field. This system irrigates a circular field unless end guns and swing lines are cycled in corner areas to irrigate more of a square field. The commonly used term, *continuous move,* is not totally accurate because the end tower moves at an adjustable time controlled start-stop operation. Intermediate towers start and stop to maintain alignment.

Figure 6–9 Solid set sprinkler system layout



Various operating pressures and configurations of sprinkler heads or nozzles (types and spacing) are located along the lateral. Sprinkler heads with nozzles may be high or low pressure impact, gear driven, or one of many low pressure spray heads. A higher discharge, part circle, sprinkler head generally is used at the extreme end of the lateral to irrigate the outer fringe of the lateral. Typically, 25 percent of lateral maintenance is spent maintaining this end gun. Each tower, which is generally mounted on rubber tires, has a power device designed to propel the system around the pivot point. The most common power units include electric motor drive, hydraulic water drive, and hydraulic oil drive.

The towers are spaced from 80 to 250 feet apart (span), and lateral lengths vary up to 2,600 feet (0.5 mile). Long spans require a substantial truss or cable system to support the lateral pipe in place. The most common lateral length is 1,320 feet, which covers about 125 to 140 acres per 160-acre field (quarter section). With proper management, application efficiencies can be 75 to 90 percent, depending on wind speed and direction, sprinkler type, operating pressure, and tillage practices.

Use of the center pivot has grown rapidly since it was first developed. Many improvements have been made. For example, some models now contain an added swing lateral unit (corner system) that expands to reach the corners of a field and retracts to a trailing position when the system is along the field edge. The corner system unit operates only in the corners. When the corner unit starts up, discharge flow in all other heads is reduced and overall field distribution uniformity is affected. These systems cover nearly 150 to 155 acres of a square 160-acre (quarter section) field. Typically 85 percent of maintenance is spent maintaining the swing lateral corner unit itself. Typically, less than adequate maintenance results in corner systems operating all the time. Total field application uniformity is reduced even further.

Many techniques have been developed to reduce energy used, lower system flow capacities, and maximize water use efficiency. They include using Low Energy Precision Application (LEPA) and Low Pressure In-Canopy (LPIC) systems. LEPA systems (precision application) require adequate (implemented) soil, water, and plant management. LPIC systems are used on lower value crops where localized water translocation is acceptable.

Advantages:

- Operating labor is reduced as compared to periodic move sprinkler systems. One individual can adequately handle 8 to 10 center pivot systems (1,000 to 1,500 acres)
- Main supply line requirements are minimized because a stationary delivery point is used.
- With good water management, relatively high water application uniformity is possible.
- With a full circle pivot, the lateral is at the starting point after one revolution.
- Because small amounts of water can be applied, it is relatively simple to maintain a high degree of water management.
- Light, frequent applications can be made.
- With adequate design and reasonably level land, systems with nozzle pressures as low as 10 pounds per square inch can be used.
- Chemical applications (chemigation) can be made through the system.
- With multiple fields, some pivot laterals can be towed to adjacent fields to be operated from several pivot points.
- Pivots can operate as part circle systems because they are capable of operating either forward or in reverse.

Limitations:

- Where the pivot point is in the center of a 160-acre field, only 125 to 140 acres are irrigated. This leaves up to 20 percent of the field nonirrigated unless special units, such as corner systems, are used to fill in the corners. Often corners are irrigated with portable laterals or solid set sprinkler systems. Graded furrow surface irrigation systems are also used for corners where soils are suitable, grades are uniform, and gated pipe is available.
- Application rates at the outer end of a low pressure center pivot lateral can be 30 to 50 inches per hour (in/hr) for periods of 10 to 15 minutes, depending on the length of the lateral and nozzle configuration. This can lead to translocation (or runoff) of applied water and erosion where adequate soil surface storage is not provided. When using sprinkler heads discharging large droplet sizes, soil surface compaction may increase towards the outer edge of the circle. The longer the pivot lateral and smaller the wetted diameter of each sprinkler or spray head, the greater the application rate.

- Light, frequent irrigations help minimize translocation and runoff, especially with low pressure systems. This increases potential water evaporation losses and may not be ideal for crops grown or water supply and system management. The irrigator must manage soil moisture more intensely throughout the season than with other systems. Otherwise, soil moisture shortages can occur.
- Because this system is relatively expensive compared to other irrigation systems, center pivot systems are often designed to barely meet, or even fall short of meeting, peak daily crop water use. Unless the system is designed to fully meet peak daily use, it generally cannot keep up in extended periods of extremely hot and dry conditions during maximum crop water use. An irrigation system should never be designed to depend on adequate rainfall to occur during the irrigation period unless the producer adequately understands and fully accepts the risks involved. If the producer accepts these risks, that a statement in writing may be obtained to forestall future litigation.
- With the radial distance from the pivot point, such concentric band includes a larger irrigated area. Thus, the most water must be carried toward the outer end of the lateral. This results in lower pressures at the end of the lateral and higher friction losses along the pipe, which translates into higher pumping costs when compared to a linear move sprinkle irrigation system or other sprinkler irrigation systems.
- When a large end gun or corner system is used for the corners, a booster pump at the end of the lateral is typically used. When the booster pump to supply water to the large end guns and corner systems comes on, all other sprinkler heads throughout the length of the pivot lateral have less discharge. Overall field distribution uniformity is affected.
- Maintenance costs of center pivot laterals with corner systems is high, compared to standard pivot systems.

Planning and design considerations:

An irrigation equipment dealer can use a computer program provided by each center pivot system manufacturer to perform a detailed design specific for that make and model of pivot. Because sprinkler pipe size and head spacing combinations are unique for each manufacturer, this is the only way accurate, detailed designs can be prepared. The farmer is generally provided with a detailed copy of the design and nozzle configuration. Evaluating this information (including the nozzling package) is always the first step when providing a detailed field evaluation on a specific pivot system.

As a service to a cooperator, NRCS can review pivot designs prepared by others to assure the proposed application provides adequate water to satisfy the needs of the crop(s) and match the available water capacity of the soil, and that it does not have negative impacts on field or farm resources (soil, water, air, plants, animals, and human considerations) including soil erosion, offsite sedimentation, and pollution of surface and ground water. The planning technician can provide daily crop water use and soil resource information, including limitations, to the irrigation decisionmaker for use by the designer.

Each pivot system manufacturer has a selection of carefully designed packages from which to select. Each package has certain application characteristics. The planning technician must be able to supply the land user with information on desirable characteristics so that the user can work with the dealer to select an optimum system package for the field. NRCS personnel, irrigation dealers, manufacturers, and the user need to work together as a team to get the best system for onsite conditions installed and properly operated.

Resource site and system features that should be provided include:

- Maximum and normal irrigation water requirements of the crop(s).
- Intake rate or maximum application rate for the most limiting or restrictive soil, tillage practices, and available surface storage.
- Translocation, runoff, and erosion potential.
- Suitability of crop for irrigation method and system.
- Available water capacity of limiting soil.
- Actual crop rooting depth(s).
- Irrigation decisionmaker management skill and labor required.

Maximum application rate for a pivot takes place in the area between the outer two tower assemblies. The application rate typically ranges from 2 to more than 50 inches per hour. **The application rate is depen-**

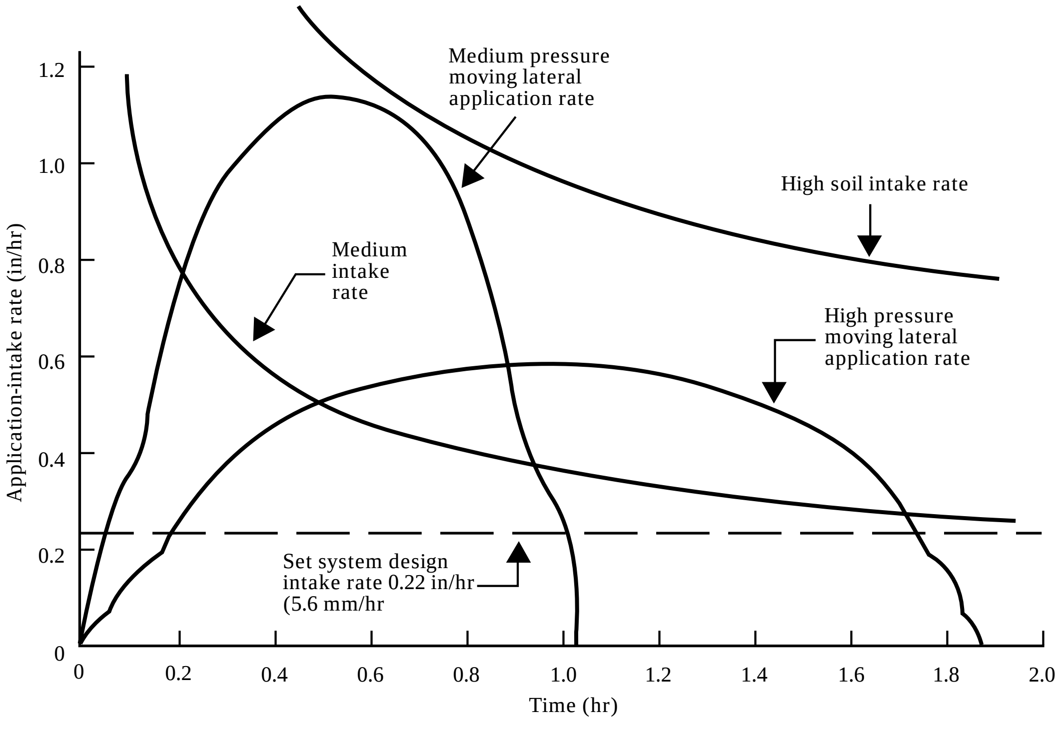
dent on type of sprinkler heads, width of spray pattern, system capacity, and distance from the pivot point. Application rate is constant for a specific point regardless of lateral rotation speed. Application volume (depth) is totally independent on the lateral rotation speed. The narrower the width of spray pattern, the higher the application rate. Low pressure spray heads typically have a narrow width of spray pattern. Because of this narrow spray pattern, LEPA and LPIC systems can have application rates exceeding 30 to 50 inches per hour for short time periods.

Sprinkler nozzles on continuously moving lateral systems apply water in a stationary pattern similar to an ellipse. Application rates at a point a given distance perpendicular to the pivot lateral begin at zero until droplets begin impacting. They reach a maximum when the center of the sprinkler head (lateral) is directly above the point, and decrease again to zero when the trailing edge of the application pattern passes the point. The depth applied at the given point is represented by the area under the application rate versus time curve. To achieve a uniform depth of application over the entire area of the circle (field), application rates must increase as the distance from the pivot point increases. Elapsed time of application decreases.

As can be seen in figure 6–10, intake characteristics of a soil are a function of rate over time. When application rates are greater than the soil intake rate curve, a potential for translocation or runoff occurs unless soil surface storage is provided. For a given application amount, the wider the wetted sprinkler pattern, the less the application rate. Narrower (typically lower pressure) wetted sprinkler pattern sprinkler nozzles provide greater application rates. Table 6–5 displays typical wetted patterns and operating pressures of various sprinkler heads on center pivot systems.

The speed of lateral rotation normally varies from 12 to 120 hours per revolution. With a center pivot system, the application rate (in/hr) at any one location is the same, regardless of the speed of rotation. However, the greater the lateral speed the less total water is applied in a given area for a given rotation. The speed (typically designated as percentage of the time

Figure 6–10 Typical soil intake and sprinkler application rate curves



moving) of a center pivot system generally is controlled by the end tower, called the master or control tower. A system of alignment controls keeps the other towers in line with the master tower. To maintain alignment, the towers are continually in start-stop operation. If a tower gets stuck and cannot move, the system shuts down (if automatic system shutoff is functioning).

With a properly designed, maintained, and managed center pivot system, water application depth is relatively uniform over the length of the lateral after several rotations. The start-stop characteristics of the system can cause nonuniformity in a small area on one rotation. With additional rotations, nonuniformity due to start-stop action of individual towers is minimized. Overall system maintenance is important. Clogged sprinklers, improperly functioning flow regulators, and improper system pressures quickly degrade uniformity of application. Applicator maintenance is most important towards the outer end of the lateral because of the large area covered by only a few nozzles.

Table 6–5 Typical operating pressures and wetted diameter patterns

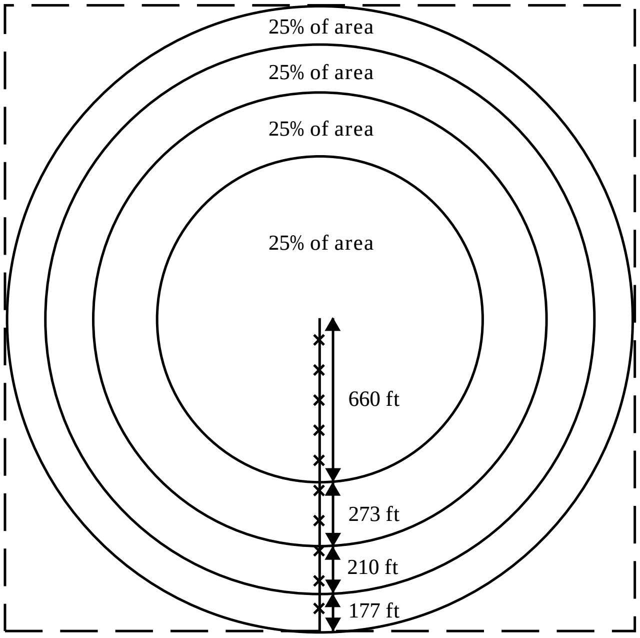
System	Operating pressure (lb/in^2)	Wetted diameter (ft)
Heads mounted on top of lateral pipe		
High pressure impact	75 +	160
Medium pressure impact	50 - 75	100 - 130
Low pressure impact	35 - 50	40 - 100
360-degree spray, low pressure	20 - 35	20 - 40
180-degree spray, low pressure	20 - 35	10 - 20
Rotating spray	15 - 50	up to 70
Spray booms, low pressure	20 - 35	120
Heads mounted on drop tubes		
Fixed spray, low pressure	20 - 35	20 - 40
Rotating spray	15 - 50	up to 60
LPIC application devices 1/	5 - 10	5 - 15
LEPA application devices 2/	2 - 10	2 - 5

1/ LPIC = Low Pressure In Canopy
2/ LEPA = Low Energy Precision Application

Figure 6–11 shows percent of total area of application versus radius for a quarter-mile-long lateral.

Occasionally, pivots up to a half mile long are installed. These pivots have very high application rates in the outer quarter to third of the irrigated area and can work properly only under certain conditions. Most important of these conditions are:
- Topography must be flat enough to allow high application rates at the outer part of the circle without significant translocation, runoff, and erosion.
- Soil must have a relatively high intake rate.
- Soil surface storage (surface roughness).
- Crops that can be established under high application rates are grown.
- Cultural practices that promote surface residue utilization for improved soil condition and surface storage, such as pitting, are implemented and maintained throughout the irrigation season.

Figure 6–11 Application area along a quarter-mile-long pivot system lateral



Percent of area	Lateral length	Acres
100	1,320 ft	125.66
75	1,143 ft	94.24
50	933 ft	62.83
25	660 ft	31.42

Many combinations of application devices, flow regulators, applicator spacing, lateral pipe sizes, tower spacing, operating pressures, application rates and spray characteristics exist. Drop tubes that have low pressure spray heads located a few inches above the ground surface or canopy are often used instead of sprinkler heads attached directly to the lateral. Drop tubes and lower pressure (larger droplets) reduce wind and evaporation losses.

Center pivot systems can be operated as either high or low pressure systems. Low pressure systems are becoming more desirable because of reduced energy use. Where pressure (flow) regulators are not required, pressures of 5 to 10 pounds per square inch in the lateral are used for Low Energy Precision Application (LEPA) and Low Pressure In Canopy (LPIC) systems. Center pivots used as LEPA and LPIC require temporary soil surface storage because of very high application rates; otherwise, surface water translocation and runoff occur. Temporary surface storage, plus infiltration during the application period, must be capable of storing the planned application amount per irrigation. Surface storage can be provided with surface residue, soil roughness, or small basins. Adequate soil surface storage must be available throughout the irrigation season.

Some center pivot systems use a large partial circle, hydraulic-revolving gun type sprinkler at the end of the lateral line. This sprinkler extends the irrigated diameter of the pivot to help fill in corners of the field. The area covered by the gun seldom receives as much water as the remainder of the field. Generally, this is the area producing the poorest yields. Typically over 75 percent of total maintenance is required by the end gun.

A total system economic analysis of inputs and outputs needs to be made to determine whether increased crop yields from the irrigated area served by the end gun covers costs. Costs include lower total field water application uniformity, reduced water supply for the remainder of the field, increased tillage area, and increased labor to maintain the end gun.

Recommendations for reducing operational problems associated with center pivot sprinkler systems:

Crops can be planted in circular rows around the center pivot system rather than planting in straight rows. Circular planting results in 94 percent of the rows being longer than those in traditional fields. This type planting reduces wheel traction problems for the center pivot machine, increases irrigation uniformity, and can reduce runoff and soil erosion. A very light water application should be used to leave tire tracks as a guide for planting equipment. Always apply water when creating guide markings. Weight of water in the pipeline can extend the lateral length several feet compared to it's empty lateral length.

Tower wheel rutting problems can be a severe operational problem where medium textured soils with poor structure become wet. As a rut deepens, it collects water and saturates the soil thus increasing the rutting problem. Erosion can occur in the ruts on sloping fields as a result of the concentrated flow. Using boom-backs to place the spray behind the tower helps to alleviate this problem.

Irrigation uniformity can be improved by smoothing the land under the center pivot system to remove any minor undulations and localized steep slopes. Best results are achieved using a cropping system that maintains crop residue at the ground surface. A no-till system of residue management is a desirable alternative.

Use furrow pitting and diking in the outer quarter of the irrigated area. Various machines can be used to make dikes or basins in the furrow area every few feet. Applied irrigation water and precipitation are stored to prevent translocation and runoff.

In arid and semiarid areas, pre-irrigation (irrigation before the soil is prepared for planting) may be a desirable management practice. The idea is to at least partly fill the root zone with moisture before working the soil and planting the crop. This helps create a deep root system and stores moisture for use during periods when the sprinkler system is unable to keep up with crop needs. Pre-irrigation is seldom needed in humid areas.

For maximum efficiency the system should move just fast enough to prevent excessive runoff. Frequently, center pivot irrigation systems are operated at too high speed. Experience has shown frequent irrigation often seals the soil, reduces water infiltration, and increases evaporation. Excessive speed also causes unnecessary wear and tear on the equipment. In arid areas 0.25 to 0.50 inch of the application amount can be lost to soil and plant evaporation with each revolution. Thus when water supplies are short or become short, consider sacrificing part of the crop area and slowing the pivot to apply more water with each rotation. Eliminating irrigation on part of the circle for the latter part of the season may be more beneficial and provide a higher quality product on the fully irrigated portion.

Deep chiseling or ripping may be beneficial to remove root and water restrictive tillage pans and temporarily increase soil intake rate (particularly on clay loam soil). This is an expensive field operation, and unless the cause of compaction is corrected, the operation must be repeated. Heavy equipment, tillage when wet, excess tillage, or poor soil condition often cause tillage pans to reoccur.

Design procedures:

The hydraulic design of a center pivot sprinkler system is complex. Today, most systems are designed using one of several computer programs usually by the company proposing to do the installation. The following equation can be used for guidance to determine if maximum application rates and depths of water applied by center pivot sprinklers are in accordance with NRCS standards. NEH, Part 623 (Section 15), Chapter 11, Sprinkle Irrigation, reviews detailed design procedures.

Given:

R = 1,350 ft
d’ = 0.3 in
T = 24 hr/d
Area = 131.4 acres

System capacity:

$$Q = \frac{453\,A\,d'}{T} = \frac{453 \times 131.4 \times 0.3}{24} = 744\,\text{gpm}$$

where:
Q = system capacity (gpm)
A = area irrigated (acres)
T = actual operating time (hr/d)
d’ = daily gross depth of application required during peak use rate period (in)
R = maximum radius irrigated (ft). Also include length of corner system if applicable

Application rate:

As a moving lateral sprinkler system moves across a point in the field, the application rate varies from zero to maximum and returns to zero. With center pivots, both the average application rate and the maximum application rate increases the further the point in the field is located from the pivot. To calculate the average and maximum application rate along a center pivot lateral, the total lateral capacity and radius can be used. Equations are provided as follows:

$$I = \frac{2(96.3)rQ}{R^2 w} \quad \text{or} \quad I_x = \frac{245rQ}{R^2 w}$$

where:
I = average application rate at point r (in/hr)
Q = system capacity (gpm)
r = radius from center of pivot to point under study (ft)
w = wetted width of sprinkler pattern (ft)
R = maximum radius irrigated (ft)
I_x = maximum application rate at any point r (in/hr) (assuming elliptical application pattern of sprinkler head with a multiplier of 4/π)

Where r, R, Q, and w are held constant:

$$I_x = 1.25I$$

(2) Low energy precision application (LEPA) systems

LEPA is a low energy precision water application system that supplies water at the point of use. This system combines a self moving mechanical device (center pivot or linear move) along with water and soil management to produce retention and efficient use of all water received (precipitation and irrigation). The soil surface and residue management provide adequate water infiltration and temporary surface water storage. The LEPA management program provides near zero water translocation or runoff.

Advantages:

- The LEPA method of distributing water is a relatively new total management systems approach to pivot and linear system irrigation. The only association with a center pivot and linear sprinkler systems is with the actual mechanical system itself. LEPA systems distribute water directly onto or very near the ground surface, below the crop canopy through drop tubes fitted with low pressure (5 to 10 lb/in^2) application devices. Because system operating pressures are low, pumping energy is reduced compared to standard systems.

- Lower system capacities per unit area are generally used for LEPA as compared to conventional surface and sprinkle systems. This method of applying water close to the ground surface essentially eliminates wind drift and evaporation losses especially after the crop has gotten taller than 18 inches. With adequate soil (tillage and residue) management, translocation and field runoff are eliminated. Practically all losses result from deep percolation below the crop root zone. These losses can be minimized if the irrigation decisionmaker follows an adequate program of irrigation scheduling. Application efficiencies of 95 percent and an application device discharge coefficient uniformity of more than 96 percent should be the objectives of the irrigation decisionmaker. The concept of precision irrigation should prevail with operation and management of LEPA systems.

Limitations:

LEPA is generally used on field slopes of 1 percent or less on a significant portion of the field. Planned maximum water application depth per irrigation or precipitation event should not exceed soil surface storage volume less infiltration during the event. Application rates exceeding 30 inches per hour, for short periods of time, have been measured on the outer end of low pressure center pivot laterals. LEPA requires cultural and residue management practices that provide adequate season-long soil surface storage. Basins constructed with furrow pitting or diking equipment is required, especially on low and medium intake soils. The small basins hold irrigation and precipitation until total infiltration occurs, thus eliminating runoff and improving water distribution uniformity.

Planning and design considerations:

LEPA systems must be capable of conveying and discharging water within a single furrow area. Water is typically confined between two adjacent crop rows. The application device is typically attached to the end of drop tubes that are located or positioned in either every furrow or in alternate furrows. Discharge devices must place water near or directly onto the soil surface. For precision application of irrigation water using LEPA systems, circular rows must be used with center pivots and straight rows with linear systems. Application devices should distribute and confine the water to the furrow area without eroding furrow dikes or crop beds. To optimize water placement, planting should be done to match the travel pattern and location of the drop tube applicators.

Minimum system capacity should be based on local crop ET needs for crops grown in the crop rotation, accounting for the available water capacity of specific soils in the field.

Some minor land grading may be needed to remove localized high and low areas in the field to provide uniform application device heights above the soil surface between towers. Spacing and location of drop tubes must coincide with crop row spacing. Water must not be applied into the tower track. Cross flow from adjacent furrows to the wheel track should also be avoided.

LEPA application devices should contain flow control devices or pressure regulators, or both, where needed. Application devices are normally convertible to at least two of the following modes: bubble, flat spray, chemigation, and drag sock. The application device should distribute the water within or across the furrow width without causing erosion of the crop bed, dams, and dikes, and thus diminishing soil surface storage.

Soil surface storage**—**The following provides field storage capacity and sizing of typical basins at 0 percent field slope:

Storage (in)	- - - - - Basins - - - - - every row	alt row	Basin dimensions top width (in)	bot. width (in)	Dike space (in)	Row space (in)
2.0	x		18	6	60	36
1.0		x	18	6	60	60

(3) Low pressure in canopy (LPIC) systems

LPIC is a low energy, low pressure, center pivot or linear move water application system that applies water within the crop canopy near the ground surface. It is similar to low energy precision application (LEPA) systems, but does not have as restrictive site and water application conditions. LPIC irrigation systems typically have some local translocation of applied water, but no field runoff. In most areas local translocation is interpreted as having water on the soil surface no further than 30 feet ahead of or behind the lateral position. Good soil and water management are required to obtain potential application efficiencies in the high 80's.

Advantages:

- The LPIC method of distributing water within the crop canopy can be installed on soils and topography unsuitable for the LEPA management system. LPIC systems distribute water through drop tubes fitted with low pressure (5 to 10 lb/in^2) application devices. Because system operating pressures are low, pumping energy is reduced compared to above canopy or high pressure center pivot and linear move systems.
- With good water and soil management and medium to coarse textured soils, LPIC irrigation systems have been successfully used on slopes up to 6 percent. Good soil condition and adequate soil surface storage for applied water (precipitation and irrigation) are essential. Terracing may be required to control rainfall and irrigation induced erosion on steeper slopes.
- Lower system capacities per unit area generally are used for LPIC as compared to above canopy sprinkle irrigation systems. In-canopy applications essentially eliminate wind drift and evaporation losses especially after the crop has grown taller than 18 inches. With proper water and soil management, application efficiencies of at least 85 percent can be obtained. Application device discharge coefficient uniformity can be more than 90 percent.

Limitations:

- LPIC is generally used with field slopes of 3 percent or less on a significant portion of the field. Maximum application depth per irrigation or precipitation event should not exceed soil surface storage less infiltration during the event. Excellent soil condition and surface storage must be maintained throughout the irrigation season. Application rates in excess of 30 inches per hour, for short periods of time, have been measured at the outer end of low pressure center pivot laterals.
- Even with proper water and soil management, LPIC irrigation systems generally are not suitable for use on low intake soils.
- Maintaining dikes or basins is difficult on soil slopes greater than 3 percent.
- Terraces may be needed to prevent erosion on slopes greater than 2 percent.

Planning and design considerations:

Low pressure in canopy (LPIC) systems must be capable of applying water without significant translocation or field runoff. Application devices on drop tubes can be spaced from 2 to 10 feet. Experience has shown crop yields are adversely affected because of poor application uniformity when using a wider spacing. Nonuniformity exists with any drop tube spacing greater than every other row. Many irrigation decision-makers feel reducing the initial investment by using a wider application device (and drop tube) spacing is justified.

Application devices should deliver water to the furrow area without eroding furrow dikes, dams, or crop beds. Planting orientation should match the travel pattern or direction of lateral movement. A very light water application can be used to leave tire tracks to guide planting equipment. Always apply water when creating guide markings. Weight of water in the lateral pipeline can extend the length several feet.

Minimum system capacity should be based on local crop ET needs for crops grown in the crop rotation, accounting for the available water capacity for specific soils in the field.

Some minor land grading may be needed to remove small high and low areas in the field to provide a near uniform application device height above the soil surface between lateral towers. Spacing and location of drop tubes need to coincide with crop row spacing and the location of the rows within the lateral span of the mechanical irrigation system. Water should not be applied into the tire track. Cross flow from adjacent furrows to the wheel track should also be avoided.

LPIC application devices should contain flow control devices or pressure regulators, or both, where needed. Application devices are normally operated in the flat spray mode. These devices should distribute water uniformly across the soil surface without excessive crop interference. The LPIC system is used for center pivot and linear move laterals. LPIC is a low pressure within canopy system. It is similar to LEPA, but does not have the site and application restrictions. It may not have the precision application required of LEPA and is more likely to have translocation and erosion problems.

(4) Linear (lateral) move sprinkler irrigation systems

A linear move sprinkle irrigation system is a continuous, self-moving, straight lateral that irrigates a rectangular field. The commonly used term, continuous move, is not totally accurate because the lateral moves in a timed start-stop operation. The system is similar to the center pivot lateral in that the lateral pipe is supported by trusses, cables, and towers mounted on wheels. A linear move sprinkle irrigation system is similar to a side roll wheel line system because it irrigates a rectangular field with uniform sized nozzles and spacing throughout the length of the lateral.

Most linear systems are driven by electric motors located in each tower. A self-aligning system is used to maintain near straight line uniform travel. One tower is the master control tower for the lateral where the speed is set, and all other towers operate in start-stop mode to maintain alignment. A small cable mounted 12 to 18 inches above the ground surface along one edge or the center of the field guides the master control tower across the field.

Linear move systems can be equipped with a variety of sprinkler or spray heads. Drop tubes and low pressure spray heads located a few inches above ground surface or crop canopy can be used instead of sprinkler heads attached directly to the lateral. Both options reduce wind and evaporation losses.

Linear move systems can be operated as either high or low pressure systems. Low pressure systems are becoming common because of reduced energy use. Low pressures of 5 to 10 pounds per square inch (plus 4 pounds per square inch with pressure regulators) are used where linear systems are used as Low Energy Precision Application (LEPA) and Low Pressure In Canopy (LPIC) systems.

Where linear move systems are used as LEPA and LPIC, temporary soil surface storage is necessary to limit surface water translocation or runoff because of the high application rates. Temporary surface storage, plus infiltration during the application period, must be capable of receiving the application amount per irrigation. Surface storage can be provided with surface residue, small basins, or both. Surface storage must be available throughout the irrigation season. Application rates are medium to high.

Advantages:

The major advantage of linear move sprinkler irrigation systems is that all the field is irrigated. Application uniformity can be high because the laterals are nearly continuously moving. Because of the potential for high application uniformity and the ability to put on small amounts of water (at higher lateral speeds), several forms of chemigation are practical.

Limitations:

The major disadvantages of linear move sprinkle irrigation systems are high initial cost, high annual operating cost, and need to supply water to the moving lateral. Generally, this type system is used on medium to high value crops and for multiple crop production areas. Unlike center pivots, when laterals reach the edge of the field and irrigation is complete, the laterals must be moved. They are either moved back (dead headed) to the starting position or moved endwise to an adjacent field. When moving the lateral endwise, tower wheels must be rotated 90 degrees or be placed on individual tower dollies.

Planning and design considerations:

NEH, Part 623 (Section 15), Chapter 11, Sprinkle Irrigation, page 11–109, provides details concerning design. Manufacturers' technical data should be consulted for additional machine specific up-to-date information.

Field layout and water source delivery methods must be considered when planning and designing a linear move system. Figure 6–12 displays typical alternatives for field layout showing water source locations. Water can be supplied to the moving lateral system by using an engine driven centrifugal pump or by using pipelines and risers to move water under pressure.

An engine driven centrifugal pump mounted on board the master control tower can lift water from a concrete lined ditch and provide pressure to sprinklers on the moving lateral pipeline. The engine also runs a DC generator to provide power for tower drive motors. The ditch can be located anywhere in the field perpendicular to the lateral, but is generally located in the center of the field or along one edge. The ditch must be installed on a relatively flat grade to provide adequate water depth without overtopping. A moving end dam checks water moving in the concrete lined ditch and provides submergence over the pump suction pipeline inlet. A screen on the pump suction pipeline helps to prevent debris from entering the lateral.

Water under pressure can be supplied to the moving lateral irrigation system via a buried pipeline and risers. The pipeline must be located perpendicular to the moving lateral, typically in the center of the field or along one edge. Typically a flexible hose connects the moving lateral pipe to riser valves on the buried pipeline. Riser connect/disconnect can be manual or automated.

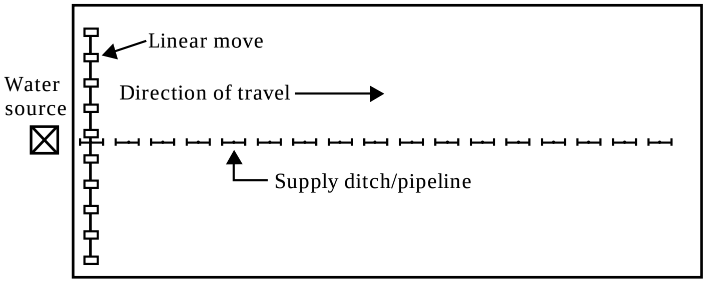
When operated manually, the system must be stopped with each mainline outlet (riser) change. Spacing of outlet risers is dependent on the length and size of hose the irrigator is able to drag from one outlet riser to the next. A small tractor can tow the hose, thereby allowing wider spacing of outlet risers. Slower lateral speeds and higher application amounts keep manual labor and the wear and tear on the hose to a minimum.

When riser connect/disconnect is automated, a powered valve opener proceeds the moving lateral dragging the supply hose in search of the next riser. If a riser is not found, the valve opener returns to the master tower and repeats the search process.

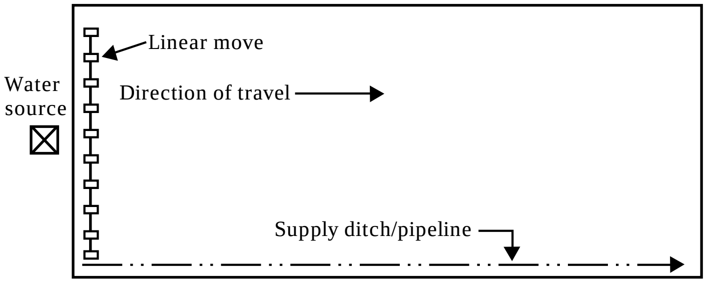
Upon locating a riser valve, the valve opener aligns itself over the riser, secures the valve body, and opens the valve. Water pressure in the forward supply hose signals a rear valve body and supply hose to disconnect. The rear powered valve body with supply hose moves towards the lateral, searching for the next riser. When secured, water pressure in the rear valve body and hose signals the forward valve body to

Figure 6–12 Typical field layout of linear systems

Supply ditch/pipeline center of field



Supply ditch/pipeline along field edge



disconnect. The moving lateral proceeds down the field as water is supplied alternately by forward and rear valve connections.

(e) Traveling gun sprinkler irrigation systems

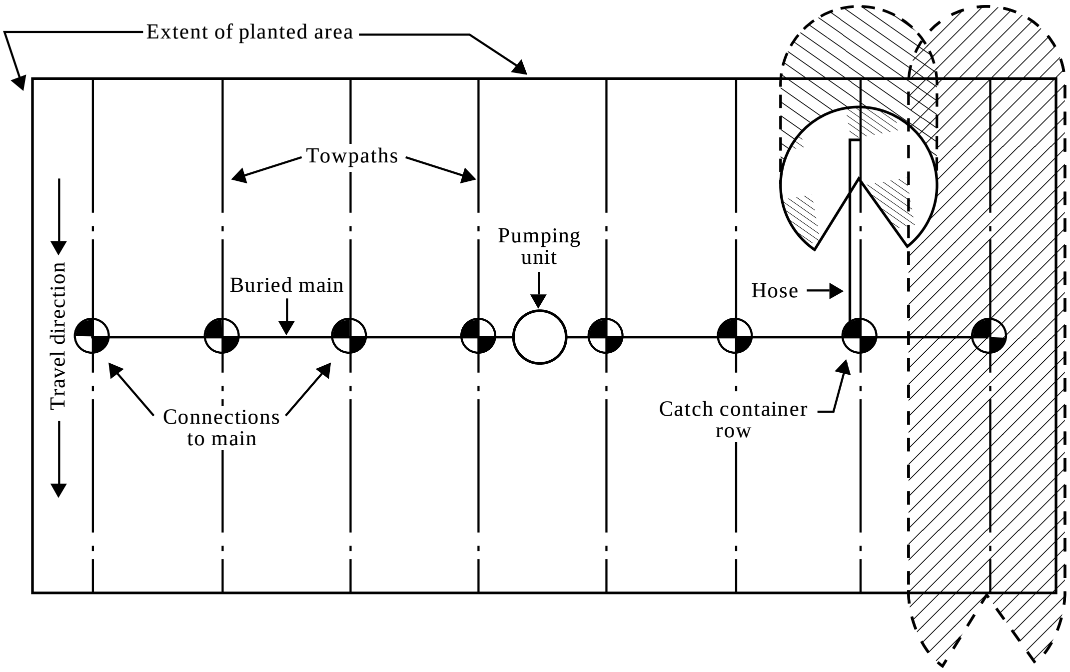
The traveling gun (traveler, gun, big gun) is a high-capacity, single-nozzle sprinkler fed with water from a flexible hose that is either dragged on the soil surface or wound on a reel. The gun is mounted on wheels and travels along a straight line while operating. The unit is equipped with a water piston or water turbine powered winch that reels in an anchored cable or hose. Some units have a small auxiliary gasoline engine to power the reel. This eliminates the water pressure required to operate the reel, and the hose speed is consistent. The cable guides the unit along a path and tows a high-pressure flexible hose connected to the water supply system. Figure 6–13 displays a typical traveling gun type system layout.

Application depth is regulated by the speed at which the hose or cable reel is operated or by the speed of a self-contained power unit. Traveling sprinklers are well adapted to odd shaped fields and to tall field crops, such as corn, if wetting adjacent areas is not a problem.

As the traveler moves along its path, the sprinkler wets a 200- to 400-foot-wide strip of land. After the unit reaches the end of a travel path, it is moved and set to water an adjacent strip of land. The overlap of adjacent strips depends on the distance between travel paths, diameter wetted by the sprinkler, average wind speed, and application pattern of the sprinkler used. The sprinkler is reset by towing it to the edge of the field.

Sprinkler discharge flows can range from 50 to more than 1,000 gallons per minute with nozzles ranging from 0-.5 to 1.75 inches in diameter and operating pressure from 60 to more than 120 pounds per square inch. Table 6–6 displays typical discharges and wetted diameters for gun type sprinklers with 24 degree angle

Figure 6–13 Traveling gun type sprinkler system layout



of trajectory and tapered nozzles operating when there is no wind. The three general types of traveling gun sprinklers are cable reel, hose reel, and self-powered/propelled.

Cable reel—The cable reel unit has a large gun type sprinkler mounted on a 4-wheel chassis equipped with a water piston or turbine-powered winch that reels in an anchored cable. The cable guides the unit along a path as it tows a high-pressure, flexible, lay-flat hose that is connected to the water supply system. The typical hose is 4 to 5 inches in diameter and up to 660 feet long. This allows the unit to travel up to 1,320 feet. After use, the hose can be drained and wound onto a reel.

Hose reel—The hose reel unit is equipped with a water turbine or gasoline auxiliary engine to power the hose reel. The hose reel can be located either at the sprinkler or at the water source (pipe outlet valve). When included with the sprinkler, a 4-wheel chassis carries the hose reel and sprinkler, which is pulled in by the hose attached to a water source (pipe outlet valve). The hose is usually flexible, reinforced, polyethylene material and is typically between 4 and 5 inches in diameter. Generally, the maximum hose length is 850 feet. This allows the unit to move 1,700 feet.

Self-powered/propelled—This unit has a self-contained pump and is self-propelled by drive wheels. A gun type sprinkler is mounted on top of the unit. The machine straddles a supply ditch and is guided by the ditch.

(1) Advantages

- Odd shaped fields can be irrigated with automated equipment.
- Manual labor is minimized.
- Suitable on sandy or high intake rate soils.
- Suitable for irrigating several different fields in a crop rotation.

(2) Limitations

- Traveling gun type sprinklers are not suitable on low intake rate soils or soils that tend to surface seal as a result of puddling.
- The turbines to power the winch and fittings on hose fed systems require additional water supply pressure. Because of the typical field size and the desire to keep costs down, it is tempting to reduce the flexible hose size for the length required. Decreased capital cost is a trade-off for increased energy cost. An energy cost analysis should be made. When possible, manufacturers' technical data should be used to make the analysis.

Table 6–6 Typical discharges and wetted diameters for gun type sprinklers with 24° angles of trajectory and tapered nozzles operating when there is no wind

Sprinkler pressure	Sprinkler discharge and wetted diameter — tapered nozzle size (in)									
	0.8		1.0		1.2		1.4		1.6	
(lb/in²)	gpm	ft	gpm	ft	gpm	ft	gpm	ft	gpm	ft
60	143	285	225	325	330	365	—	—	—	—
70	155	300	245	340	355	380	480	435	—	—
80	165	310	260	355	380	395	515	455	675	480
90	175	320	275	365	405	410	545	470	715	495
100	185	330	290	375	425	420	575	480	755	510
110	195	340	305	385	445	430	605	490	790	520
120	205	350	320	395	465	440	630	500	825	535

- To cast a droplet of water over 50 feet requires a droplet size greater then 0.25 inch to resist air friction. Well graded soils and soils low in organic matter are subject to puddling or surface compaction, thus further reducing soil intake rate and increasing potential translocation. Some crops may also be damaged by large droplet sizes.
- To adequately irrigate edges of the field, water is applied outside of the field boundaries.

(3) Planning and design considerations

Large gun type sprinklers require the highest pressures of any sprinkler system. In addition to the high operating pressure required at the sprinkler nozzle, hose losses can add another 20 to 40 pounds per square inch to the total system dynamic pressure head (TDH). Therefore, gun type sprinklers are well suited to supplemental irrigation where seasonal net irrigation requirements are small. This helps to mitigate the high power costs associated with high operating pressure. An energy cost evaluation should be made. Traveling gun sprinklers can be used where crops and irrigation needs are rotated from field to field. Table 6–7 displays friction loss in flexible pressure irrigation hose used on traveling gun type sprinklers.

Distribution uniformity is typically fair in the inner part of a 100- to 200-foot-wide strip; however, along the ends and sides it is poor. Typically, the ends and sides of the strip are inadequately irrigated. Application uniformity of large gun sprinklers is adversely affected by wind speeds of more than 5 miles per hour. A gun type system is not recommended in windy areas.

Power requirements to drag a hose depend on the size of hose, soil texture, soil moisture conditions, and crop. Pull energy requirement is greatest on wet, bare, sticky soils and less on wet vegetation or bare, sandy soils. On sticky soils the tow paths for the traveling unit and hose should be left in grass or other vegetation. Excessive wear to the hose can occur on soils containing sharp or abrasive rock fragments.

Guidelines for sizing traveling gun type sprinkler hoses are shown in table 6–8. Table 6–9 displays recommended maximum travel lane spacing as a function of wetted diameter and average wind speed. The gross depth of water applied for continuous moving large gun type sprinkler heads is given in table 6–10.

Table 6–7 Friction loss in flexible irrigation hose used on traveling gun type sprinkle system

Flow	Friction Loss (lb/in^2/100 ft)					
	hose size (in)					
(gpm)	2 1/2	3	3 1/2	4	4 1/2	5
	lb/in^2 per 100 ft					
100	1.6	0.7	0.3			
150	3.4	1.4				
200	5.6	2.5	1.4	0.6		
250		3.6		0.9		
300		5.1	2.6	1.3	0.6	
400			2.3	1.3		
500			3.5	2.1		
600				4.9	2.7	1.1
700				3.6	2.1	
800					4.6	2.7
900						3.4
1000						4.2

Table 6–8 Guidelines for sizing traveling gun type sprinkler hoses

Flow range (gpm)	Hose diameter (in)
50 to 150	2.5
150 to 250	3.0
200 to 350	3.5
250 to 500	4.0
500 to 700	4.5
> 700	5.0

Table 6–9 Maximum travel lane spacing for traveling gun type sprinklers as a function of wetted diameter and wind speed

Wetted diameter	- - - - - - - - - - Wind speed (mi/hr) - - - - - - - - - -			
	> 10	5–10	0–5	0
	- - - - - - - Percent of wetted diameter - - - - - -			
	50	60	70	80
	Maximum travel lane spacing - - - - - - - - - - - - - - - - - - (feet) - - - - - - - - - - - - - - - - -			
200	100	120	140	160
300	150	180	210	240
400	200	240	280	320
500	250	400	350	400
600	300	360	420	480

Table 6–10 Gross depth of water applied for continuous moving large gun type sprinkler heads [1/]

Sprinkler flow (gpm)	Spacing between travel lanes (ft)	Depth of water applied - - - - - - - - - - - - - - - - Travel speed (ft/min) - - - - - - - - - - - - - - - - 0.4	0.5	1	2	4	6	8	10
		- - - - - - - - - - - - - - - - - - inches - - - - - - - - - - - - - - - - - -							
100	165	2.4	1.9	1.0	0.5	0.24	0.16	0.12	0.09
200	135	4.9	3.9	2.0	1.0	0.5	0.32	0.24	0.19
	200	4.0	3.2	1.6	0.8	0.4	0.27	0.2	0.16
300	200	6.0	4.8	2.4	1.2	0.6	0.4	0.3	0.24
	270	4.4	3.6	1.8	0.9	0.4	0.3	0.22	0.18
400	240	6.7	5.3	2.7	1.3	0.7	0.44	0.33	0.27
	300	5.3	4.3	2.1	1.1	0.5	0.36	0.27	0.21
500	270	7.4	6.0	3.0	1.5	0.7	0.5	0.37	0.29
	330	6.1	4.9	2.4	1.2	0.5	0.4	0.3	0.24
600	270	8.9	7.1	3.6	1.8	0.9	0.6	0.45	0.36
	330	7.3	5.8	2.9	1.5	0.7	0.5	0.36	0.29
700	270	10.4	8.3	4.2	2.1	1.0	0.7	0.5	0.42
	330	8.5	6.8	3.4	1.7	0.8	0.6	0.4	0.34
800	300	10.7	8.5	4.3	2.1	1.1	0.7	0.5	0.43
	360	8.9	7.1	3.6	1.8	0.9	0.6	0.4	0.36
900	300	12.0	9.6	4.8	2.4	1.2	0.8	0.6	0.5
	360	10.0	8.0	4.0	2.0	1.0	0.7	0.5	0.4
1000	330	12.2	9.7	4.9	2.4	1.2	0.8	0.6	0.5
	400	10.0	8.0	4.0	2.0	1.0	0.7	0.5	0.4

1/ (equation) average depth of water applied = 1,605 x (sprinkler flow, gpm) / (land spacing, ft) x (travel speed, ft/min)

(4) Design procedures

NEH, Section 623 (Section 15), Chapter 11, Sprinkle Irrigation, pages 11–84 to 11–89, provides a detailed explanation of design procedures and an example. This material should be used as a design guide. Applicable equations include:

Application rate:

Traveling sprinkler:

$$I_t = \frac{C\,Q}{R^2\,\text{Deg}}$$

where:

I_t = approximate average application rate from traveling gun (in/hr)
C = unit conversion constant = 13,624
Q = gun discharge (gpm)
R = wetted radius of nozzle (ft)
Deg = portion of circle receiving water (degrees). Usually does not exceed 270°.

Stationary sprinkler:

$$I_t = \frac{C\,Q}{R^2}$$

where:

I = approximate average application rate from a stationary large gun (in/hr)
C = unit conversion constant = 30.7
Q = gun discharge (gpm)
R = wetted radius of nozzle (ft)

Application depth:

$$F_n = \frac{C\,Q\,\text{Eff}}{W\;S}$$

where:

F_n = net application depth (in)
C = unit conversion constant = 1.605
Q = gun discharge (gpm)
Eff = estimated application efficiency (decimal)
W = tow path spacing (ft)
S = travel speed (ft/min)

(f) Traveling boom sprinkler irrigation systems

A traveling boom system is similar to a traveling gun system except a boom containing several nozzles is used. The boom can be moved by a self-contained, continuously moving power unit by dragging or coiling the water feed hose on a reel. The boom usually rotates, but may be fixed. A boom can be nearly 100 feet long with discharge nozzles spaced uniformly along the boom. Nozzle discharge patterns on the boom overlap one another. Back pressure from fixed nozzles rotates the boom.

Field tests indicate distribution uniformity for traveling boom sprinklers can be higher than traveling guns for the same diameter of coverage. A nonrotating boom can start and stop near the edge of a field, thereby providing adequate irrigation to these areas.

(1) Advantages

- Can be fabricated locally in any good farm machine shop.
- Can save labor after initial installation.

(2) Limitations

- High maintenance requirements.
- Lack of commercial dealers and support for replacement parts

(3) Planning and design considerations

Design of a traveling boom sprinkler system is similar to a traveling gun type system. Operating pressures are generally much less than for large gun type sprinklers. The edge and end effect is less than that for large gun type sprinklers because the wetted diameter of individual nozzles is much less. Local shop fabricated self-propelled booms can be effective and apply water efficiently on small farms growing high value specialty crops, such as berries, fresh vegetables, and melons.

652.0603 Micro irrigation systems

(a) General

Micro irrigation is the broad classification of frequent, low volume, low pressure application of water on or beneath the soil surface by drippers, drip emitters, spaghetti tube, subsurface or surface drip tube, basin bubblers, and spray or mini sprinkler systems. It is also referred to as drip or trickle irrigation.

Water is applied as discrete or continuous drops, tiny streams, or miniature spray through drip emitters or spray heads placed along a water delivery line called a lateral or feeder line. Typically, water is dispensed from a pipe distribution network under low pressure (5 to 20 lb/in^2) in a predetermined pattern. The outlet device that controls water release is called an emitter. Water moves through the soil from the emission point to soil areas of higher water tension by both capillary and gravity forces. The amount of soil wetted depends on soil characteristics, length of irrigation period, emitter discharge, and number and spacing of emitters. Number and spacing of emitters are dependent on the spacing and size of plants being irrigated. If water management is adequate, line source emitters can be used for row crops. Micro irrigation can efficiently distribute an otherwise limited water supply.

With proper water management, application efficiencies for a well designed, installed, and maintained micro irrigation system can be in the range of 80 to 90 percent for the area irrigated. Without proper water management, they are typically 55 to 65 percent. By far the greatest water management problem is over-irrigation.

Principal uses for micro irrigation systems are providing water for windbreaks, vegetables, berries, grapes, fruit, citrus and nut orchards, nursery stock, and landscape and ornamental plantings. Figure 6–14 shows a typical micro irrigation system layout in an orchard. In areas where the water supply is inadequate and water cost is high, subsurface micro systems can be cost effective for irrigation of high value row crops. Buried line source lateral systems have been in continuous operation since 1982.

(b) Types of micro irrigation systems

(1) Point-source emitters (drip/trickle/bubbler)

In the point-source form of micro irrigation, water is applied to the soil surface as discrete or continuous drops, tiny streams, or low volume fountain through small openings. Discharge is in units of gallons per hour (gph) or gallons per minute (gpm) over a specified pressure range. Discharge rates typically range from 0.5 gallon per hour to nearly 0.5 gallon per minute for individual drip emitters.

Microtubes (spaghetti tubing) are classed as point-source emitters even though they are actually tubes rather than emitters. Microtubes consist of various lengths of flexible tubing that is small in diameter (.020 to .040 inch). Typically, no other water control device is used. Discharge rates are adjusted by varying the length of the tubing. The longer the tube, the greater the friction loss, which decreases the discharge rate.

Because discharge orifices are small, complete filtration of water is required. Bubblers are commonly used with ornamental landscape plantings, orchards, and grape vineyards. Flows are generally less than 1 gallon per minute. Figure 6–15 illustrates typical drip emitter devices.

Figure 6–14 Typical orchard micro system layout

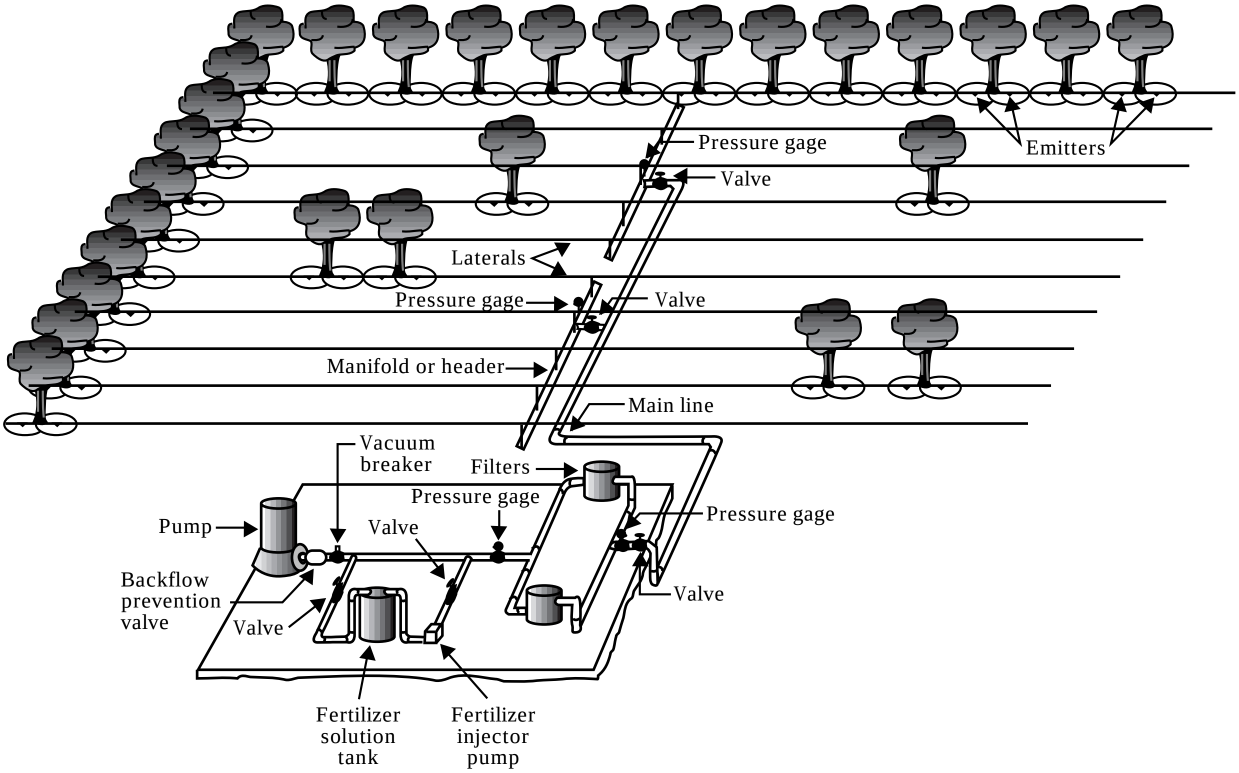
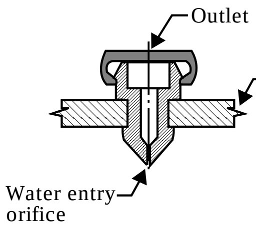
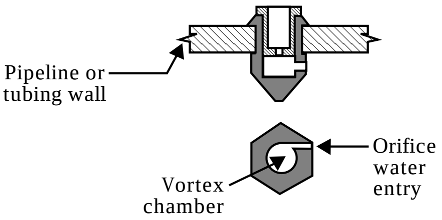


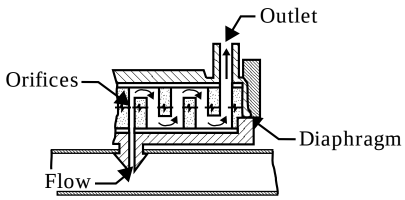
Figure 6–15 Emitter devices



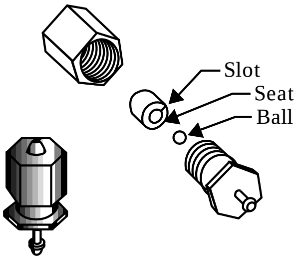
Orifice emitter



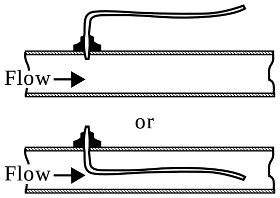
Orifice-vortex emitter



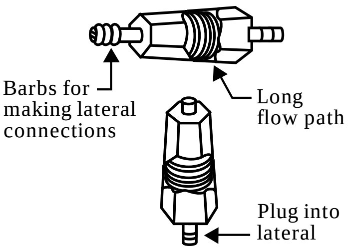
Emitter using flexible orifices in series



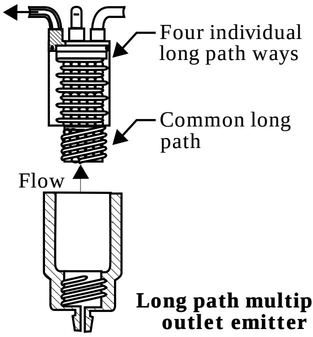
Ball and slotted seat emitter



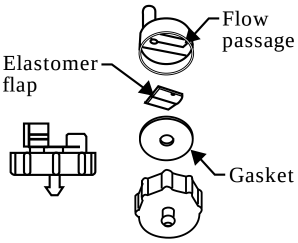
Long path emitter small tube



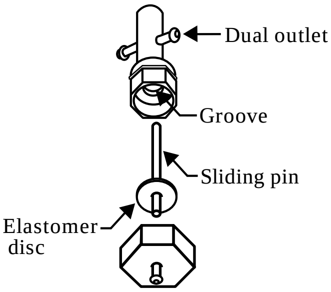
Long path emitters



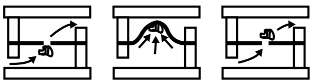
Long path multiple outlet emitter



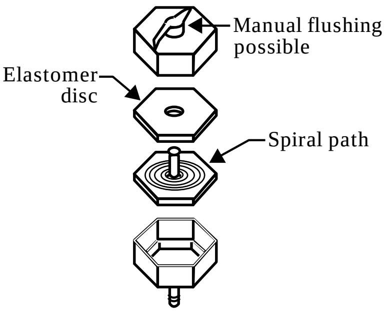
Groove and flap short path emitter



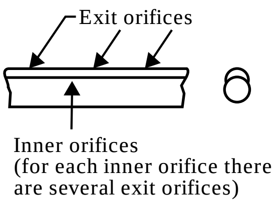
Groove and disc short path emitter



Continuous flow principle of multiple flexible orfices



Compensating long path emitter



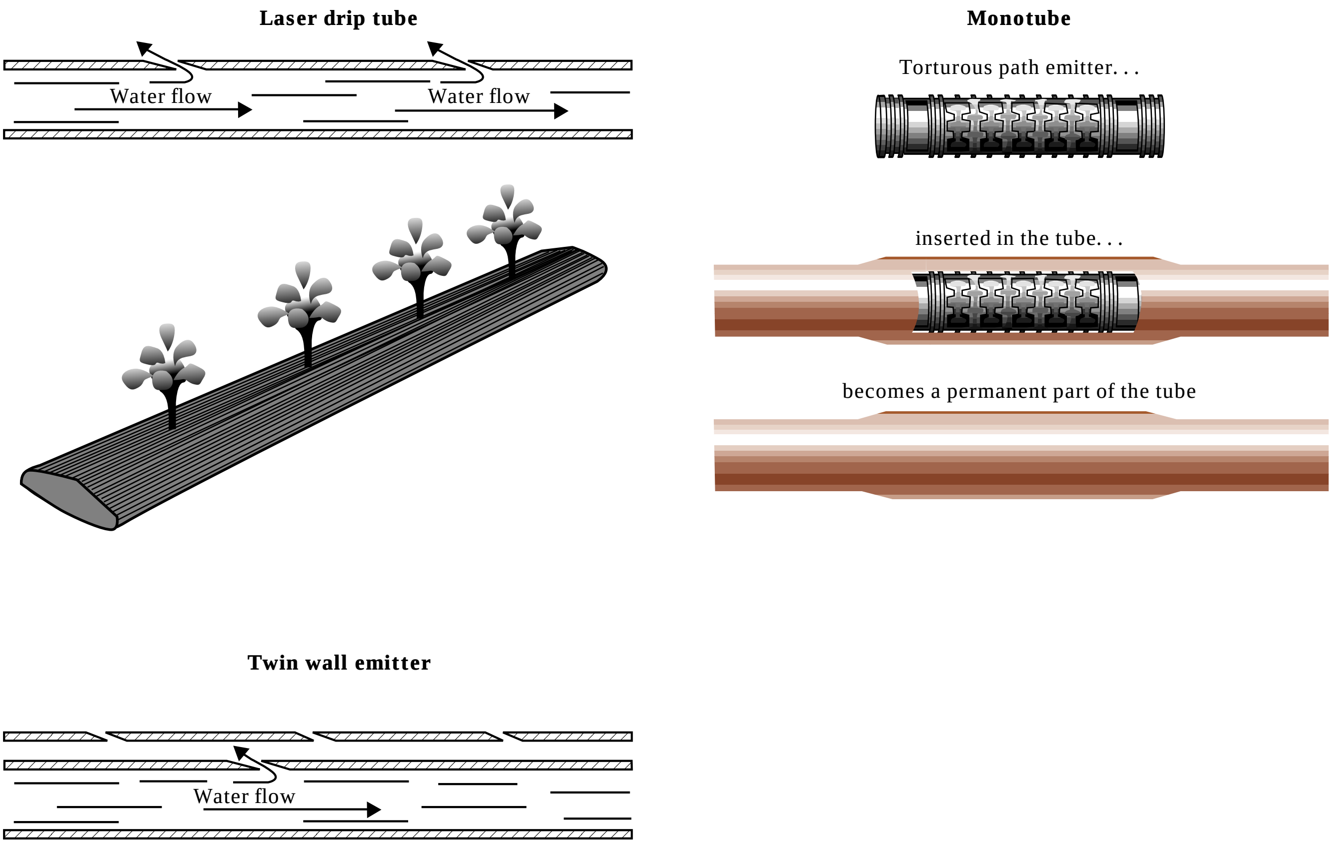
Twin-wall emitter lateral

(2) Surface or subsurface line-source emitter systems

This type micro irrigation uses surface or buried flexible tubing with uniformly spaced emitter points (or porous tubing). The tubing comes as layflat tubing, flexible tubing, or as semirigid tubing that retains its shape. Generally, this system is used in permanent crops, but has been used successfully as either surface or buried lines with high value row crops, such as vegetables, cotton, and melons. Figure 6–16 shows typical examples of surface and subsurface emitter devices.

Surface or subsurface line-source emitter systems have a uniform discharge in units of gallons per hour per foot (gph/ft) or gallons per minute per 100 feet (gpm/100 ft) over a specified pressure range. Because discharge orifices are small, complete filtration of water is required.

Figure 6–16 Surface and subsurface line source emitter devices



(3) Basin bubblers

The basin bubbler micro irrigation system applies water to the soil surface in small fountain type streams. The streams have a point discharge rate greater than that for a typical drip or line source system, but generally less than 1 gallon per minute. The discharge rate normally exceeds the infiltration rate of the soil, so small basins are used to contain the water until infiltration occurs. Discharge is generally from a small diameter (3/8 to 1/2 inch) flexible tube that is attached to a buried or surface lateral and located at each plant vine or tree. The typical emitter device is not used, and discharge pressures are very low (< 5 lb/in^2). Figure 6–17 displays a typical basin bubbler system.

Basin bubblers are used in orchards and landscaping and ornamental plantings. These systems are best used with medium to fine textured soils where lateral water movement can provide adequate soil moisture for the desirable plant root development area. With coarse textured soils, bubbler discharge rates are increased and shorter time periods used, thereby providing more wetted area above the potential plant root zone.

The discharge orifice is larger than that of the other systems, so little or no water filtration is required. Generally, screening of coarse debris and small creatures is sufficient. Drains must be provided to allow discharge of any collected sediment.

Flow to each discharge point is controlled by adjusting the elevation at the outflow end of the tubing. The tubing is attached to a support stake. Decreasing the elevation along the lateral compensates for head loss in the lateral.

This simple system distributes water uniformly to each tree without special flow regulating devices. Operating pressures less than 2 pounds per square inch can distribute water on up to 10 acres. Bubbler basins apply water to a larger soil volume than do drip emitters; therefore, only one outlet device is needed per plant or tree. This promotes increased root development that may be needed to support the plant in windy areas. Irrigation scheduling is also easier.

(4) Spray or mini sprinkler

With spray or mini sprinkler micro irrigation systems, water is applied to the soil surface as spray droplets from small, low-pressure heads. The typical wetted diameter is 2 to 7 feet. Discharge rates are generally less than 30 gallons per hour (0.5 gpm). The wetted pattern is larger than that of typical drip emitter devices, and generally fewer application devices are needed per plant.

Spray and mini sprinklers also have less plugging problems and less filtration required than point-source emitters (drippers). Many spray heads only require the replacement of the orifice to change discharge rate. If an orifice becomes plugged, it is easily removed and cleaned or replaced. Spray or mini sprinkler head application patterns can be full, half circle, or partial circle (both sides). Figure 6–18 illustrates typical spray and mini sprinkler type heads.

Figure 6–17 Basin bubbler system

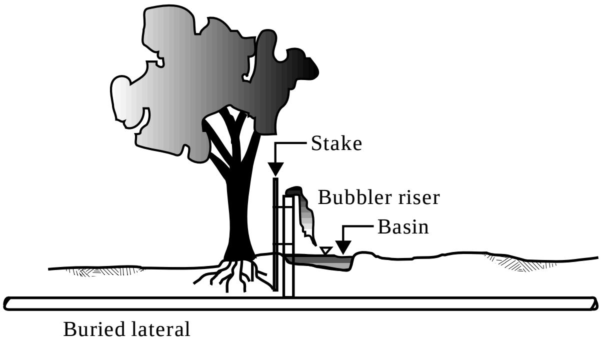
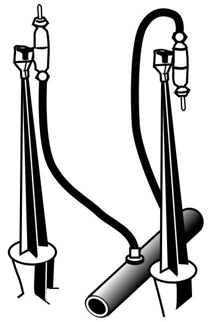


Figure 6–18 Various mini spray and sprinkler heads

Mini-sprinkler on wedge

Composed of mini-sprinkler, coupler (cantal), flexible pvc tubing (2 ft), plunger, wedge.

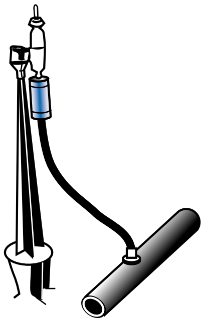
Flow in gph at 20 lb/in^2	Color code
4	blue red
6	blue blue
13	gray black
15	black black
24	blue black
26	red black
35	brown black



Mini-sprinkler on wedge with pressure regulator

Composed of all components listed in mini-sprinkler on wedge 1 with addition of pressure regulator (regulated working pressure of 30 lb/in^2) (2 atm).

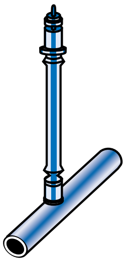
Flow in gph at 30 lb/in^2	Color code
16	gray black
18	black black
29	blue black
32	red black
42	brown black

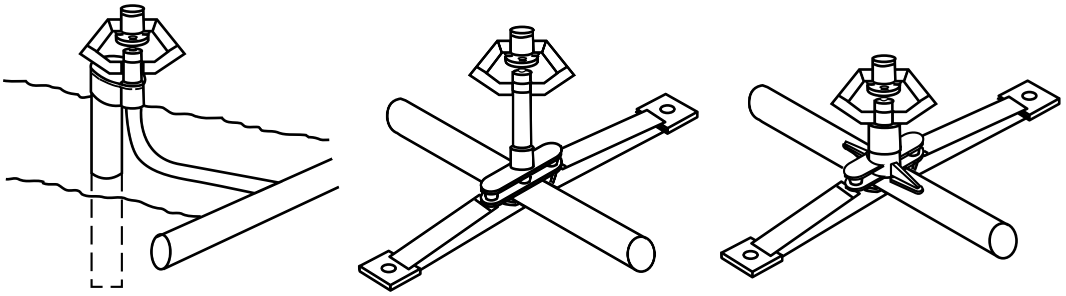


Mini-sprinkler on flexible riser

Composed of mini-sprinkler, flex riser, plunger.

Flow in gph at 20 lb/in^2	Color code
4	blue red
6	blue blue
13	gray black
15	black black
24	blue black
26	red black
35	brown black





(c) Advantages of micro irrigation systems

Micro irrigation can be one of the most efficient methods of irrigation. Little if any runoff and little evaporation occur, and deep percolation can be controlled with good water management. Water is applied at the point of use (plant transpiration). Other advantages of micro irrigation systems are:

- Systems are easily automated with soil moisture sensors and computer controlled for low labor requirements.
- Soil moisture levels can be maintained at predetermined levels for start-stop operation.
- Fertilizer can be efficiently added to irrigation water. With proper water management, there is minimum waste caused by deep percolation, and less opportunity for ground water pollution.
- Much of the soil surface remains dry, reducing weed growth and soil surface evaporation.
- The soil surface remains firm for use by farm workers and equipment.
- Frequent irrigations can be used to keep salts in the soil water more diluted and moved away from plant roots. Irrigation with water of higher salinity is possible (requires a high level of management). Where salts are present, soil-water movement must always be toward the edges of the wetted bulb (away from roots). A common mistake is to shut the system down when precipitation occurs, often creating soil-water movement into the plant root zone.
- Micro irrigation can be used on all terrain and most agricultural crops and soils and is often used on steep, rocky ground that is unsuitable for other forms of irrigation.
- Low tension water availability to plants enhances growth and improves crop yield and quality.

(d) Limitations of micro irrigation systems

Micro irrigation is considered expensive to install and maintain. In general, the cost of micro systems is greater than that for sprinkle or surface systems. Frequent maintenance is essential, and a high level of management is required to obtain optimum application efficiencies. Other limitations include:

- Clogging is a major problem in all micro systems. Emitter outlets are very small, and can be easily clogged with chemical precipitates, soil particles, or organic materials. Clogging can reduce or stop water emission. Chemical treatment of the water is often necessary, and filters are almost always required. Filtration and treatment can be costly, especially where water is taken from surface sources containing sediment and debris. During installation, care should be taken to clean all construction debris from the inside of pipelines as this material can cause plugging.
- Animals, especially rodents, can damage surface (and shallow subsurface) installed plastic pipe less than 4 inches in diameter.
- With low operating pressures, poor distribution uniformity can result because of elevation differences on undulating ground. Pressure regulators or pressure compensated emitters are then necessary. However, they require about 2 pounds per square inch for operation.
- On steep terrain, automatic gravity draining of laterals to a low point within the field can cause low distribution uniformity, especially in low pressure, high volume systems. This problem is aggravated by frequent on-off cycles, but can be overcome by installing air-vacuum valves in a raised pipe arch (i.e., dog leg) at one or more locations in the lateral. Drains are installed just upstream of each pipe arch. This increases the number of sites affected by lateral pipe drainage, thus decreasing effects on distribution uniformity because each drain discharges less water.

- When soil water is reduced in the plant root zone, light rains can move salts in surrounding soil into the plant root zone, which can constitute a potential hazard. Salts also concentrate below the soil surface at the perimeter of the soil volume wetted by each emitter. If the soil dries between irrigations, reverse movement of soil water can carry salts from the perimeter back into the root zone. To avoid salt damage to roots, water movement must always be away from the emitter and from the plant root zone. As strange as it may seem, in high soil salinity areas or when using high saline or sodic water for irrigation, one may need to irrigate when it rains.
- A smaller volume of soil is wetted at each plant. Plants can be quickly stressed if the system fails (i.e., pump failure, water source cutoff, pipeline or valve failure). Daily checking of the system is necessary even when all or part is automated. Storing a 3-day plant-water supply in the soil is recommended along with daily replacement of water used.
- Multiple emitters at each plant are recommended to decrease effects of manufacturer variability, to increase area of root development, and to reduce risk of plant damage should an emitter become plugged.

(e) System components

System components should include the following, in order of installation starting at the water source point (see fig. 6–19).

1. Prescreening of debris and settling of coarse sediments if source is surface water. Need control valves and flow measuring device.
2. Provide system operating pressure of 5 to 20 pounds per square inch using pump(s) or gravity flow. Need pressure gage and control valves.
3. Chemical injector device(s) for injecting fertilizers and other pipeline cleaning chemicals.
4. Filtering system to remove fine organic, suspended sediment and chemical precipitates. Need pressure gage upstream and downstream of filter device.
5. Filter system backflush device. Need control valves.
6. Mainlines typically are buried PVC plastic pipe with control valves as necessary.
7. Submains typically are buried PVC plastic pipe with control valves, pressure regulators, and drains as necessary.
8. Laterals or feeder lines are either surface or buried PE or PVC plastic flexible tubing.
9. Emitter devices.
10. Appropriately placed soil moisture sensing devices. Start of irrigation can be manual, computer programmed, or with a time clock. Lateral on-off sequencing can be automated with solenoid operated valves. A controller and electric valving can help assure proper irrigation timing to meet soil depletion and plant needs.

(f) Planning and design considerations

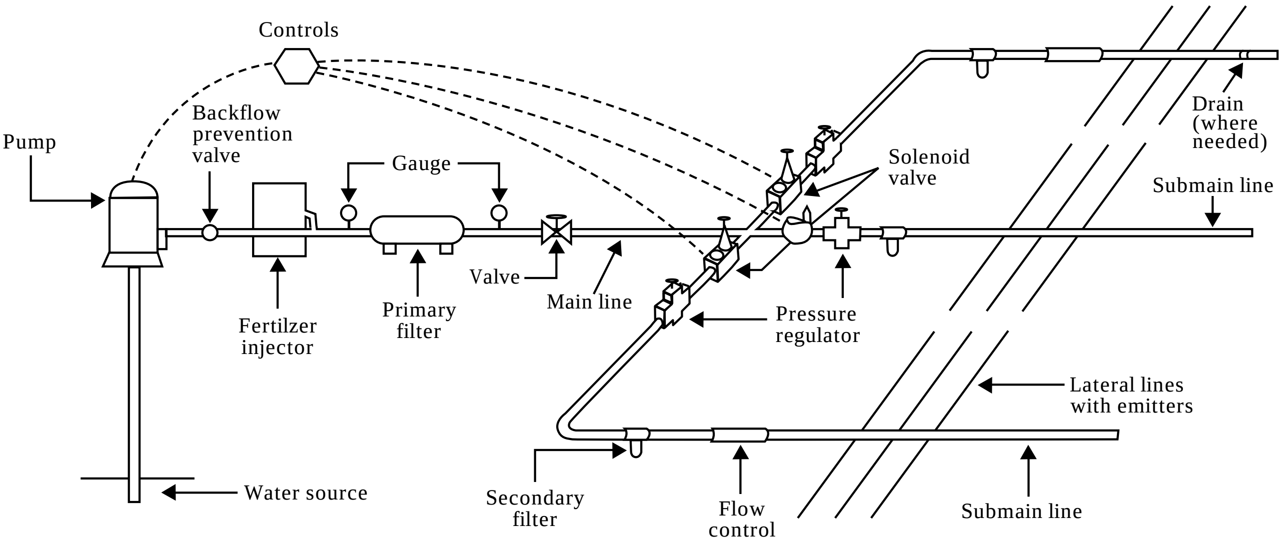
(1) Water quality

Water quality is usually the most important consideration when determining whether a micro irrigation system is physically feasible. Well and surface water often contain high concentrations of undesirable minerals (chemicals). Surface water can contain organic debris, algae, moss, bacteria, small creatures, weed seeds, and soil particles. Well water can also contain sand.

Various forms of algae are in almost all quiet surface water. Sunlight and water high in nutrients encourage algae growth. Algae are hard to remove from laterals and emitters once it gets established. The best way to handle algae is to prevent it from forming. Chlorine can be injected at the end of each irrigation cycle to help prevent algae buildup. Algae growth is especially a problem where sunlight aids algae growth inside white plastic pipe that is installed above the ground surface. Black pipe (PE pipe) is not affected because sunlight does not penetrate the pipe. White plastic pipe can be painted with a dark color to help prevent sunlight penetrating the pipe and provide some UV protection.

Bacterial slime can plug emitters and small tubing. Conditions favoring slime growth include pH of 4.5 to 6, low oxygen level, temperatures greater than 46 degrees Fahrenheit, organic matter, dissolved iron and manganese, and hydrogen sulfide. Treatment is by injection of chlorine, sodium hypochlorite (household bleach), or calcium hypochlorite (swimming pool chloride). Continuous injection of chlorine at 1 ppm is effective. Periodic shock treatment with concentrations of 10 ppm can also be used.

Figure 6–19 Micro system components



Water with a high Sodium Absorption Ratio (SAR) and low water Electrical Conductivity (ECw) destroys the structure of the soil, which results in a drastically reduced intake rate. Sodium content may also be high enough to be toxic to the plant. Unless well water characteristics are known, water should be tested for EC_w and SAR. See chapter 13 of this guide for further discussion.

If water softeners are used in a home water system, do not use the softened water in a micro irrigation system. Large amounts of salt are added to soften the water. Besides not being good for plant growth, salt precipitates at the emitter discharge orifice and tends to plug emitters. Attach the micro system into the water system upstream of any water softener.

Water with relatively high salinity (high EC_w), as defined in chapter 13, can sometimes be used with a micro system. A higher soil-moisture level (lower soil-water tension) can help assure water for plant growth is readily available. Additional irrigation water keeps the salts leached from the plant root zone. To accomplish this, the soil must have good internal drainage.

Bicarbonate concentrations in water higher than 2.0 milliequivalents per liter (meq/L), coupled with a pH above 7.5, and temperatures greater than 70 °F promotes scale development (precipitation of mineral deposits). With black plastic pipe placed on the ground surface and exposed to direct sunlight, the water temperature inside can get quite high. A scale (precipitate) is formed inside the walls of the pipe and emitters. Injections of acid (food grade phosphoric or sulfuric) can be used for cleaning, but will not completely reclaim partly blocked lines and emitters. Continual treatment is usually necessary. Treatment of water before it is used in the system allows precipitation and collection of the carbonates to occur before they get into the pipe system. Periodic treatment within the pipe system can dislodge built up scale and cause plugging of emitters.

Another common problem with well water is high iron concentration, which can result in iron precipitating in the line. This encourages the growth of iron bacteria. The resulting slime can plug emitters. Where iron is present in concentrations of 0.4 ppm or greater, it can be oxidized to form a precipitate. This precipitate should be filtered out before the water enters the irrigation system. Table 6–11 displays physical, chemical, and biological factors that cause plugging of emitters. Table 6–12 displays plugging potential from irrigation water used in micro systems.

Soil particles near 2 micron size tend to stick together because of physical size, shape, and electric charge. Under very low velocities they can clog emitter orifices. Flushing the lines regularly and using larger size emitters helps prevent clogging. Also using a chemical dispersant, such as hexamethaphosphate, can keep particles dispersed so they do not stick together.

Table 6–13 displays the typical composition and classification of water used in micro systems. It should be noted either one, two, or all three factors (physical, chemical, and biological) can be present in a micro system. The designer and irrigator need to know what is present in the irrigation water and in what concentration.

Table 6–11 Physical, chemical and biological factors causing plugging of emitters

Physical	Chemical	Biological
Organic debris	Ca or Mg carbonates	Filaments
Aquatic weeds, moss	Ca sulfate, Ferric iron	Slimes
Algae	Metal hydroxides, carbonates, silicates and sulfides	Microbial deposits
Aquatic creatures, snails, fish	Fertilizers phosphate, ammonia	iron ochre
Plastic particles	manganese	manganese ochre
Soil particles—sand, silt, clay	iron, zinc, copper	sulfur ochre

Table 6–12 Plugging potential from irrigation water used in micro irrigation systems

Problem	Low	Medium	Severe
Physical			
Suspended solids, ppm	50	50 -100	> 100
Chemical			
pH	7.0	7.0 – 8.0	> 8.0
TDS, ppm	500	500 – 2,000	> 2000
Manganese, ppm	0.1	0.1 – 1.5	> 1.5
Iron, ppm	0.1	0.1 – 1.5	> 1.5
Hydrogen sulfide, ppm	0.5	0.5 – 2.0	> 2.0
Biological			
Bacteria population - no. per mL 1/	10,000	10,000 – 50,000	> 50,000

1/ Bacteria populations reflect increased algae and microbial nutrients.

Table 6–13 Typical composition and classification of water used in micro irrigation systems

Source of water	Physical 1/		Chemical 1/	Biological 1/	
	suspended solids (ppm)	dissolved solids (ppm)	iron or manganese ppm	bacteria population number/mL	classification - physical/chemical/ biological
City water	1	500	0.05	10	0-4-0
Runoff water	300	50	0.05	10,000	10-0-6
River water	70	900	0.10	4,000	6-8-4
Well water	1	1,650	0.05	40,000	0-10-9

1/ Physical and biological composition of water can change during the season and between seasons.

(2) Clogging

Clogging of emitters is the most serious problem of micro irrigation. Properly designed and maintained filtration systems generally protect the system from most clogging. Clogging causes poor water distribution, which in turn may damage the crop if emitters are plugged for a long time. When the plant(s) shows excessive stress, it is generally too late to correct the problem. Multiple emitters per plant are recommended. The main causes of clogging are algae, bacterial slime, precipitate, construction debris, and sediment. In general, adequate filtration, line flushing, and chemical treatment prevent most clogging.

The irrigator must see or know when clogging is occurring. The capability of the irrigator to observe operation of emitters or spray heads is rated as follows. The ratings are in order of easiest to see to most difficult to see from a reasonable distance (i.e., from the seat of a small 4-wheel drive RV unit).

Type emitter		Observation
1	Basin bubblers	Water bubbling out of the pipe and water on the ground surface.
2	Spray heads	Spray coming from the heads and the resulting wetness on the ground surface and plant leaves.
3	Point emitters suspended above ground surface	Water dripping out of the emitter and the resulting wetness on the ground surface.
4	Line source and point source emitters lying on the ground surface; spaghetti tubing	The line must be picked up to see if the emitter is operating. Wetness of ground surface around the emitter can also be observed. Raising the emitter too high causes the flow rate to change.
5	Subsurface or buried tubing	Ground surface moisture caused by upward capillary action and plant condition indicate emitter operation. Buried emitters cannot be seen, and their replacement is more difficult. The Crop Water Stress Index Gun (infra red thermometer reading) can be used to detect plant stress before it is visible to the eye.

Note: The only way to be assured whether the emitter is discharging near design flow is to check it using a catch can or rain gutter trough device and a stop watch. The operating pressure also needs to be checked. A little ingenuity is often necessary to develop catch can devices that collect all the water discharging from an in-line emitter or spray head, and to measure operating pressure.

(3) Filter systems

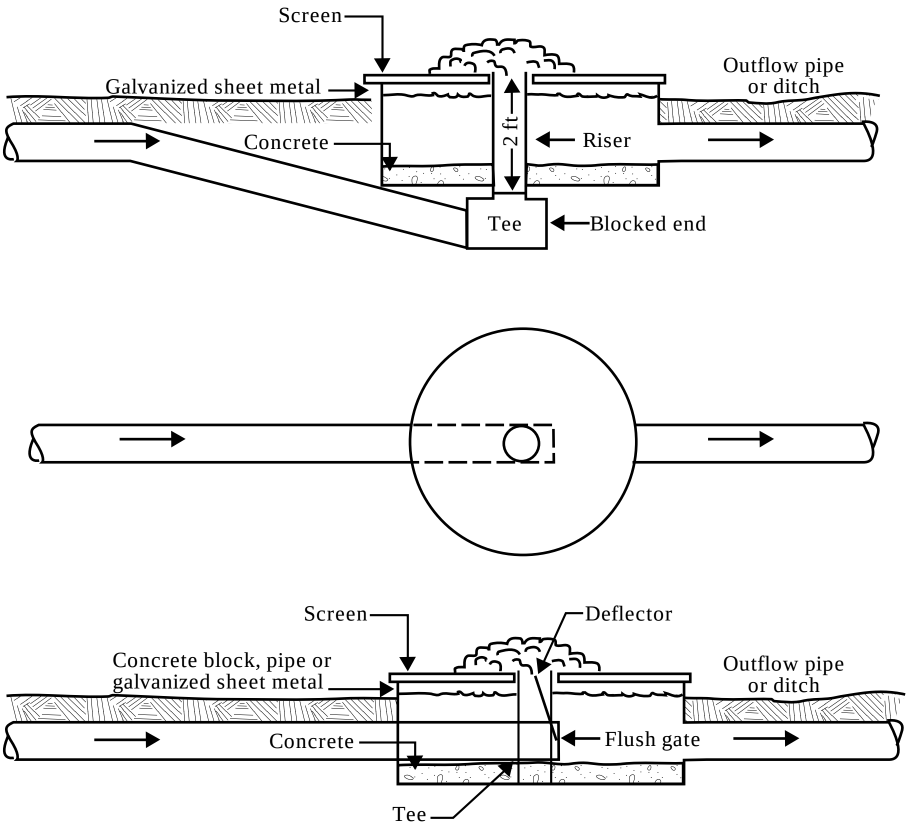
All water must be screened and filtered to some degree before use in a micro irrigation system. Water quality, temperature, flow rate, and emitter orifice size determine the type of filter. One rule of thumb is to select filters that retain all particles at least a tenth the diameter of the smallest passageway in the system. For example, a 250-micron filter would be used to remove all particles passing through a 25 micron opening. Ordinary window and door screen approximates 8-12 mesh (0.125-0.083 inches).

Surface water must first be screened to remove organic debris, weed seeds, small aquatic creatures, and coarse sediment. Self-cleaning screens provide transportation and storage outside the flow area for debris removed by the screen. When using flow-through screens, debris should remain on the screen surface unless mechanically removed or a back-flushing facility is used. Most wells produce some sand, precipitates, and particles that can cause emitters to plug. The turbulent fountain screen is effective for screening out coarse material, and it requires minimum labor for maintenance (fig. 6–20).

Filters cannot remove dissolved minerals, algae cells, or bacteria. The degree of filtration is generally given in terms of screen mesh size. The relationship of mesh size to particle size is displayed in table 6–14. Porous flexible tubing requires sand bed filters unless water is clean.

Filter types include centrifugal force, graded sand, cartridge, disc, and mechanical screens. Sand filters can be backflushed manually or automatically. Cartridge filters are generally replaceable. Relatively low cost replaceable cartridge filters can be used for small systems. When properly operated, centrifugal force separators are generally effective down to fine sand particle sizes. Disk filters separate during the backflush cycle.

Figure 6–20 Turbulent fountain screen



Recommended screen and riser pipe diameters

- - - Flow rate - - -		Screen diameter	Riser pipe diameter
(ft^3/s)	(gpm)	(in)	(in)
1	450	42	8
2	900	48	10
3	1,350	60	12
4	1,800	72	15
5	2,250	84	18

Mechanical screens are either removed and hand cleaned or backflushed. A clean well water source may require an 80 to 100 mesh filter. Normally, a 160 to 200 mesh screen contains particles unable to pass through most emitters. Generally, the finer the screen mesh the faster it plugs up. Two or more filters or a larger screen or filter area increase the time between cleaning. Multiple screen or filter systems can be cleaned while the system is in operation. Table 6–15 displays filters used in micro irrigation systems.

Sand bed filters use graded sand for the medium, either in graduated layers or single sand particles. The size and type of sand determine pore space size, which controls the degree of filtration. Pore diameter is about a seventh of the sand particle diameter. Commercial sands generally are designated by number, becoming finer as the number gets larger (table 6–14). Under flow conditions of less than 20 gallons per minute per square foot of media surface, commercial sands are efficient and have relatively large debris-holding capacity.

Table 6–14 Particle size equivalents

Particle	Microns [1]	Inches	Screen mesh
No. 11 - Granite	952	.037	
No. 10 - Silica sand	524	.021	
No. 30 - Silica sand	335	.013	
Very coarse sand	1000 - 2000	.0393 - .0786	18 - 10
Coarse sand	500 - 1000	.0197 - .0393	35 - 18
Medium sand	250 - 500	.0098 - .0197	60 - 35
Fine sand	100 - 250	.0039 - .0098	160 - 60
Very fine sand	50 - 100	.0020 - .0039	270 - 160
Silt	2 - 50	.00008 - .0020	
Clay	2	< .00008	

1/ 1000 micron = 1 millimeter.

Table 6–15 Filters used for micro irrigation systems

Type	Practical filtration limit
Settling basins	Varies with time and water chemistry (usually 100% of 40 micron size and larger particles settle in 1 hr)
Sand separators	To 74 microns
Screen filters	To 74 microns
Sand bed filters	To 25 microns
Cartridge filters	To 25 microns
Disc filters	To 25 microns

Sand filters are cleaned by backwashing (backflushing). Backwashing can be done automatically on a timed cycle, at a specified pressure drop across the filter, or manually. Facilities must be available to receive, store, and dispose backwash water, sediment, and debris. Periodic chemical treatment may be necessary to control algae in the filter bed.

Disc filter elements consist of flat, grooved rings resembling poker chips with a hole in the center. A stack of rings forms a cylindrical filtering body. Grade of filtration (400 to 25 microns) depends on the size and number of grooves in the individual grooved rings. The rings are held tightly together with a compressed spring.

The filtration process takes place throughout the entire cylinder volume (stacked rings). Water flow direction is from outside the cylinder toward the center. When properly sized (flow capacity wise) and with larger than 140 mesh screening, head losses through the disc cylinders are relatively low. Manufacturer recommended minimum operating pressures are in the range of 30 pounds per square inch, with maximum operating pressures of 100 to 200 pounds per square inch, depending on model. Backflush water (at typical pressures of 40 to 50 lb/in^2) allows the disc to separate and flush out the collected soil and debris particles that have been caught in the grooves.

A filter is one of the most important components of a micro irrigation system and must be kept clean to be effective. Monitoring line pressure at filter inlet and discharge points helps check performance and signal a change occurring in the filter.

(4) Soil moisture distribution

Micro irrigation normally wets only a part of the potential plant root zone in a soil. In arid areas, crop root development is generally limited to that volume of soil wetted from the emitter system. For agricultural crops, typically half to three-fourths of the potential root development area is wetted (irrigated). For landscape plantings, individual plants are irrigated.

The volume of soil wetted is a function of the emitter type, emitter discharge, distance between emitters, time of set, and soil texture. Distribution and extent of soil wetting should be a major consideration in the design of any micro irrigation system. For medium and fine textured soils, wetted area width from a point source is generally equal to or greater than wetted depth. With coarse textured soils, wetted width is less than wetted depth; therefore, more emitters are necessary to obtain adequate irrigation for root development.

The ability of a plant to resist dislodging by wind is determined by root development (typically plant root zone wetted pattern). This is especially the case in arid areas, and to some extent in all areas. Table 6–16 compares wetted diameter and area for various soil textures. A full surface area cover crop is difficult to maintain in an arid environment if less than complete surface area irrigation coverage is provided.

(5) Distribution lines

The micro irrigation distribution system is a network of pipes, tubing, and valves. Generally, mainlines carry water from the pump to a system of submains. Submains then carry the water to headers (manifolds) and then into laterals or feeder lines. Mainlines and submains are generally buried PVC plastic pipe. Fittings are cemented or use O-ring gaskets for water tightness. Submains can also be flexible tubing either buried or laid on the ground surface. Mainlines and submains are typically buried to provide access and limit potential equipment damage. Laterals or feeder lines are normally 3/8- to 3/4-inch-diameter polyethylene (PE) flexible tubing either buried or laid on the ground surface. Lateral fittings generally are slip joint with hose clamps for water tightness. In some areas rodents and small animals (i.e., coyotes, squirrels) will damage PE pipe that is less than 4 inches in diameter.

Table 6–16 Diameter and area of soil wetted by a single emitter with no restrictive horizons

Soil texture	Wetted diameter (ft)	Wetted area (ft^2)
Coarse	2 - 4	4 - 12
Medium	4 - 5	12 - 20
Fine	5 - 7	40 - 60

(6) Emitter application

The discharge (emitter) device is unique to a micro irrigation system. Many types, shapes, and discharge ranges are commercially available. They can be either pressure compensating or noncompensating.

Discharge devices can be divided into two general categories based on field application: line-source and point-source. Point-source include microspray or sprinkler heads, microtubing, and bubbler systems. Manufacturers of emitter devices can furnish performance data that show discharge versus pressure for each size and kind of emitter manufactured. Section 652.0605 includes additional discussion of specific emitters that are commercially available.

Line-source emitters are used for closely spaced row crops, such as vegetables, cotton, sugarcane, grapes, strawberries, melons, and some small fruit. These emitters are either a series of equally spaced orifices along a single or double chamber tube, or they are small openings in porous tubing. Closely spaced buried line source emitter tubing has been shown to be effective in small areas of turf, especially where surface spray is not desirable.

The discharge rate of line-source emitters is in gallons per hour or gallons per minute per unit length of tubing (gpm/100 ft, or gph/ft). The emitter or orifice spacing affects the location and amount of water delivered to each plant. Operating pressures range from 5 to 30 pounds per square inch. Line source emitters should be used on nearly level ground and can be installed on the ground surface or as buried feeder lines.

Point-source emitters are used for windbreaks, fruit, citrus and nut orchards, grapes, cane berries, blueberries, bananas, ornamental and landscape shrubs, nursery stock, and greenhouse crops. The point-source emitter is an individual emitter typically attached to 1/4- to 3/4-inch-diameter PE flexible tubing. Orifice flow rates vary from a half gallon per hour for drippers, 30 gallons per hour for spray heads, and 1 gallon per minute for basin bubbler devices.

(7) Miscellaneous control devices

- Gate valves provide on-off control. They can be operated manually or with timed or automatic solenoid valves.
- Pressure regulating valves control pressure within desired limits of emitter discharge.
- Vacuum relief valves prevent soil particles from entering the system when negative pressures develop (i.e., the system is shut off).
- Pressure gages monitor pressures in the system.
- Flushing valves discharge collected sediment and other debris.
- Drain valves drain water from the system.
- Injectors add chemicals (fertilizers, acid, chlorine).
- Flow measuring devices monitor how much water is applied.

(8) Fertilizing

The application of plant nutrients through a micro irrigation system is convenient and efficient. Several injectors are commercially available. Nitrogen can be injected in the forms of anhydrous ammonia, aqua ammonia, ammonium phosphate, urea, ammonium nitrate, and calcium nitrate. Some chemicals may change the pH in the water, thereby affecting other chemicals in the water. Phosphorus is usually added in acid form. Potassium can be added as potassium sulfate, potassium chloride, and potassium nitrate. Other micronutrients can be added, but may react with salts in irrigation water resulting in precipitation. Care should be taken so the injected nutrients don’t react with other chemicals in the water to cause precipitation and plugging.

(9) Costs

Equipment, filtration, control, and numerous laterals needed for a micro system generally result in a high cost per acre. Per acre costs are highly influenced by filtration costs. For example filtration requirements are relatively the same for 20 acres as for 40 acres. Adequate filtration cannot be overstressed. Because of reduced filtration requirement and number of laterals, basin bubbler and spray systems can be more economical, especially for orchards and landscaping.

(10) Maintenance

Frequent maintenance is essential to keep emitters functioning at design flow. Maintenance items include:

- Clean or backflush filters when needed.
- Flush lateral lines regularly.
- Check emitter discharge often; replace as necessary.
- Check operating pressures often; a pressure drop (or rise) may indicate problems.

- Inject chemicals as required to prevent precipitate buildup and algae growth. Inject liquid fertilizers when needed.
- Service pumps regularly.

(11) Automation

Micro irrigation systems can be operated fully automatic, semiautomatic, or manually. A time clock or programmed control panel can be installed to operate solenoid valves, to start and stop the irrigation, and to control each submain and lateral. This degree of automatic control is simple, the parts are readily available, and it effectively controls the desired amount of water to be applied. A manual priority switch that can override clock or control panel switches is desirable to postpone or add irrigations. A fully automatic system, using soil moisture sensors to provide the triggering mechanism to start an irrigation, is also simple to install and operate. Several sensors may be needed, depending on soils and rooting depth of crops to be grown. Where water supply is adequate overirrigation is the biggest water management problem with automated systems.

(g) Design procedures

The primary objective of good micro irrigation system design and management is to provide sufficient system capacity to adequately meet crop-water needs. Uniformity of application depends on the uniformity of emitter discharge, system maintenance, and elevations of the ground surface. Nonuniform discharge is caused by pressure differentials from friction loss, plugging, elevation change, and manufacturing variability. Using pressure compensating emitters somewhat alleviates the elevation change and pressure differential problem. Using multiple emitters for a single shrub, vine, plant, or tree helps to compensate for manufacturing variability and minimize plant damage that results from plugged or malfunctioning emitters.

The designer of a micro irrigation system must make a rational choice about the duration of application, the number of emitters per plant, specific type of emitter device(s), and the discharge per emitter to provide the most effective irrigation. In most situations the required water volume (or rate) to irrigate a specific crop is less than that required by other irrigation methods; thus the minimum system capacity requirement is not a limiting factor if adequate water was available for other irrigation methods.

(1) Water management

Proper water management when using micro irrigation is essential to avoid excessive water use. The ease of applying an irrigation, especially under manual control, brings a mentality of *when in doubt irrigate.* Deep percolation, typically the result of overirrigation, cannot be seen. As a result, overirrigation is by far the biggest problem with users of micro irrigation. Field application efficiencies are often measured in the mid 60 percent, while most micro irrigation systems are designed assuming application efficiencies of more than 90 percent. The irrigation system designer needs to have realistic expectations of water management skills and desires of the user.

(2) Duration of application

The least cost per acre is generally achieved by the system having the longest duration or lowest flow rate and smallest pipe sizes. The duration for application is influenced by the overall irrigation schedule and by incorporating a factor of safety in the design. Application time must be sufficient to apply the water that has been consumed since the previous irrigation. Ideally, continuous or demand delivery of irrigation water provides the lowest cost design and best irrigation scheduling opportunity. Therefore, the duration of each irrigation can be determined after the following are known:

- Gallons of water needed per plant per day to meet evapotranspiration.
- Desired interval between irrigations (frequency of irrigation).
- Application rate per emitter or unit length.

Hours operation per irrigation are determined by:

$$\frac{\text{Gallons of water per plant per day}}{\text{Application rate per plant in gallons per hour}}$$

Gallons of water needed per day per plant are calculated using the evapotranspiration rate of the plant(s), soil MAD level, and AWC of the planned soil volume.

Even if water used by an individual plant is to be replaced daily, a 3-day water supply be stored in the plant root zone to is recommended provide water when irrigation system discharge is interrupted. If the system operates less frequently than daily, increase the time of operation or the number of emitters for each plant to increase water applied each irrigation. Ideally, a system can be designed to run 24 hours per day; but most systems should run no more than 18 hours. Time is needed for general maintenance, breakdowns, and to provide a factor of safety during extreme high plant water use periods. Using more emitters of the same discharge rate with less duration is generally better than fewer emitters with greater capacity.

(3) Discharge per emitter

Drip emitters are mechanical devices designed to operate at low pressure (2 to 20 lb/in^2) from 0.5 gallon per hour to nearly 0.5 gallon per minute. Discharge rates of line source emitters are in units of gallons per hour per foot or gallons per minute per 100 feet. Discharge rate should be within plus or minus 15 percent of the average system flow rate.

(4) Number of emitters

Micro irrigation requires a decision be made about the percentage of potential rooting volume to be watered. It is recommended at least 40 to 50 percent of the area under a tree, plant, or shrub drip line (at mature size) receive moisture. Part of this requirement comes from providing an anchor system to support the plant. Plant roots do not normally develop where the soil is dry; i.e., water tension is 15 bars (atmospheres) or greater. An onsite test may be needed to determine vertical and lateral movement of water from a point source.

Typically in uniform fine to medium textured soils, the wetted width is equal to the wetted depth. In coarse textured soils, the wetted width is typically no more than half the wetted depth.

Emitters should be spaced equidistant around the shrub or tree and should be located within a third of the distance from the trunk to the drip line. With line source emitters, 12- to 36-inch spacing is typical. In coarse textured soils, line source emitters should be spaced less than 12 inches apart, and medium textured soils less than 24 inches. Emitter spacing also depends on plant type and density.

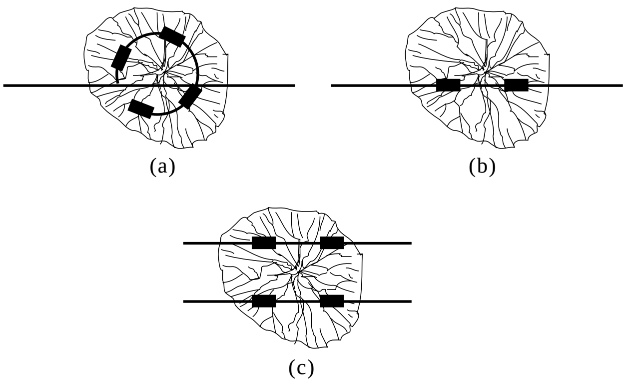
Microspray or sprinkler heads provide the largest wetted soil volume. A minimum of two application devices should be used per shrub or tree. Figure 6–21 displays alternative ways to layout emitters for individual trees.

(5) Laterals or feeder lines

Most lateral or feeder lines are flexible PE plastic tubing. Emitter devices are either attached directly to the pipe or the pipe may contain built-in orifices. Surface installed tubing is subject to damage from animals, rodents, and field operating equipment. The designer should be guided to size laterals so that discharge differences are kept to less than 10 percent between the first and last emitter on the line. Even though pressure compensating emitters may be used, lateral friction loss must be evaluated to help assure minimum pressures are maintained for proper emitter (and regulator) operation. Table 6–17 displays maximum pressure variation for typical emitters.

Most micro systems are divided into subunits connected by manifolds through control valves to a submain or mainline that feeds several laterals. The total pressure variation in both the manifold and laterals must be considered when sizing pipelines. In an optimum design, the total pressure loss in the subunit should be equally divided between the manifold and the laterals. For example, if a total of 4 pounds per square inch pressure variation is allowed, 2 pounds per square inch can be lost in the manifold and 2 in the laterals.

Figure 6–21 Alternative emitter layout



(6) Mainlines and submains

Mainlines and submains (including manifolds) are generally buried PVC plastic pipe. Laterals or feeder lines need to be installed as nearly level as possible. On sloping fields submains and mainlines should be installed up and down the slope. A 5-foot elevation change represents over 2 pounds per square inch pressure change, which can change emitter discharge more than the allowable 10 percent in low pressure systems.

To maintain uniform pressure at outlets to laterals the designer should consider the following:

- Divide the submains into shorter lengths or off balance the outlets so less than a 10-foot drop is present between inlet from the mainline and lowest outlet to a lateral pipeline.
- Install pressure regulators at each outlet to laterals.
- Install flow regulators at each outlet to laterals.
- Use pressure compensating emitters where needed.
- Size submains and laterals to reduce and sometimes nearly eliminate friction losses.
- Provide adequate pressure to operate pressure and flow regulators at design discharge.

(7) Other

When planning, the designer must determine total irrigation system needs. These needs include settling basins, screens, filters, pumps, flow meters, fertilizer injectors, chlorine or acid injectors, mainlines, submains, laterals, emitters, valves (both manual and electric valves for automatic operation), pressure gauges, drains, timer clocks, and soil moisture monitoring devices. Not all systems require all equipment.

(8) Basic information needed for planning and design

- Topographic map with 2-foot contour interval including field shape, layout, dimensions, and elevations of key points.
- Soil series, texture, AWC, and MAD level for crop(s) grown, crop ET, area, and volume of soil to be wetted by micro system.
- Tree, shrub, or crop—type, size, location, spacing, and plant density.
- Water source—quantity, quality, location, delivery schedule, water measuring device(s).
- Desirable surface or subsurface emitter system and laterals or feeder lines.
- Water screening and filtering system and settling basins.
- Submains, mainlines, valves, pressure gages, pressure and flow regulators, and injectors.
- Power supply: type, location.
- Pumping plant.
- Future expansion including mature tree size, interplantings of new trees, and different crops to be grown in a rotation.
- Growers desire as to level of operation and automation, management skills available, and irrigation scheduling.

Table 6–17 Recommended maximum pressure variation, in pounds per square inch, for typical emitters [1]

	Nonpressure compensating		Pressure compensating	
Design pressure	15	20	15	20
Pressure variation [2]	13 -17	17 - 23	11 - 20	14 - 26
Pressure range	4	6	9	12

1/ Based on 20 percent flow rate variation.
2/ The allowable pressure variation is an estimate for typical point source emitters.
If available, manufacturers' discharge data should be used instead.

(9) Design steps

The steps necessary for the design of a micro system include:

Step 1. Determine net depth of application

$$F_n = \frac{C\,Q\,N\,T\,E}{A\,f}$$

where:

C = 1.604 as units conversion factor
Q = discharge rate in gph per emitter per foot of lateral
N = number of outlets (application devices, emitters) or total length of lateral tubing in feet
T = hours of operation per day (suggest a maximum of 18 hr/d)
A = area of field in square feet served by number of emitters
E = overall field application efficiency, including irrigation scheduling (expressed as a decimal with a maximum of 0.90)
f = percent of total area to be wetted (as a decimal)

Step 2. Emitter design.

Step 3. Determine flow per lateral, submain, and mainlines. Determine total system capacity to meet design plant evapotranspiration.

Step 4. Size laterals, submains, and mainlines.

Step 5. Determine pump size needed.

Step 6. Determine screening, settling basin, and filter system needs.

Step 7. Determine fertilizer injector needs.

Step 8. Determine chlorine and acid injector needs.

Step 9. Determine number and location of pressure gauges, valves, drains, and measuring devices needed.

Step 10. Provide how to determine plant water need (irrigation scheduling).

Step 11. Prepare irrigation system operation, management, and maintenance plans.

Example designs are included in section 652.0605. Master blank design worksheets are included in chapter 15 of this guide.

(10) Installation

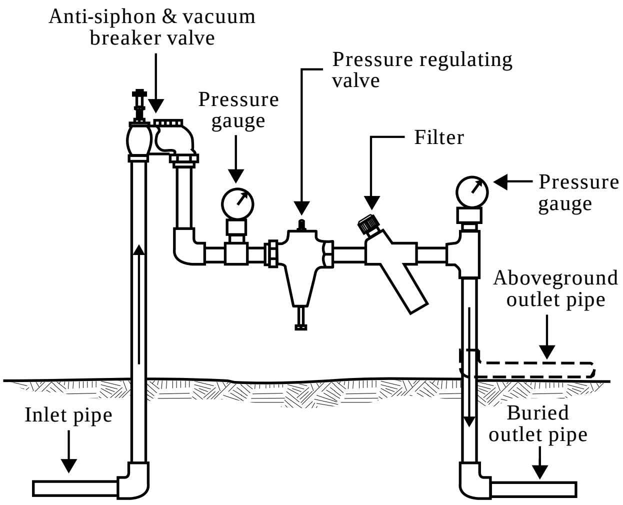
All pipelines and tubing should be designed to permit draining and flushing to remove foreign matter that can clog emitters. All pipelines should be drained to prevent freezing, algae growth, and other such problems.

Pressure gauges should be installed at the inlet and outlet end of each filter. These gauges aid in determining when the filter needs to be cleaned or backwashed. For automatic backflushing systems, a threshold pressure differential is set to initiate backflush operations.

Surface installed lateral or feeder lines should be snaked to allow for contraction and expansion caused by temperature change. Add 5 to 10 percent to the length for expansion and contraction (snaking). Microtubing used as minilaterals at each plant allows the mainline to adjust to temperature and to move while emitters or minisprinklers on the microtubing laterals remain in place.

Figure 6–22 displays a typical small system hookup that can be installed on a domestic water source.

Figure 6–22 Typical small system hookup



(h) Windbreaks

Irrigation of windbreaks can be desirable for one of two purposes:

- To establish the windbreak.
- To maintain the windbreak throughout its life

The type of micro system and how it is installed, operated, and maintained is dependent on purpose and type of trees or shrubs to be irrigated (fig. 6–23).

Windbreak micro system design can be complicated because different tree and shrub sizes and spacings may be included in the layout. Lateral emitter spacings or capacities may vary with each row, which can require a separate design for each lateral. Drought tolerance should be developed over several months or years by encouraging deeper root development patterns. Longer, less frequent irrigations encourage deeper root development. Design methods in NEH, part 623, (section 15), chapter 7, can be used when the purpose of the system is to irrigate a windbreak throughout its life. Chapter 4, Irrigation Water Requirements, and the state supplement of this guide provide local water requirements for shrubs and trees.

When establishment of the windbreak is the objective, the following additional factors must be considered:

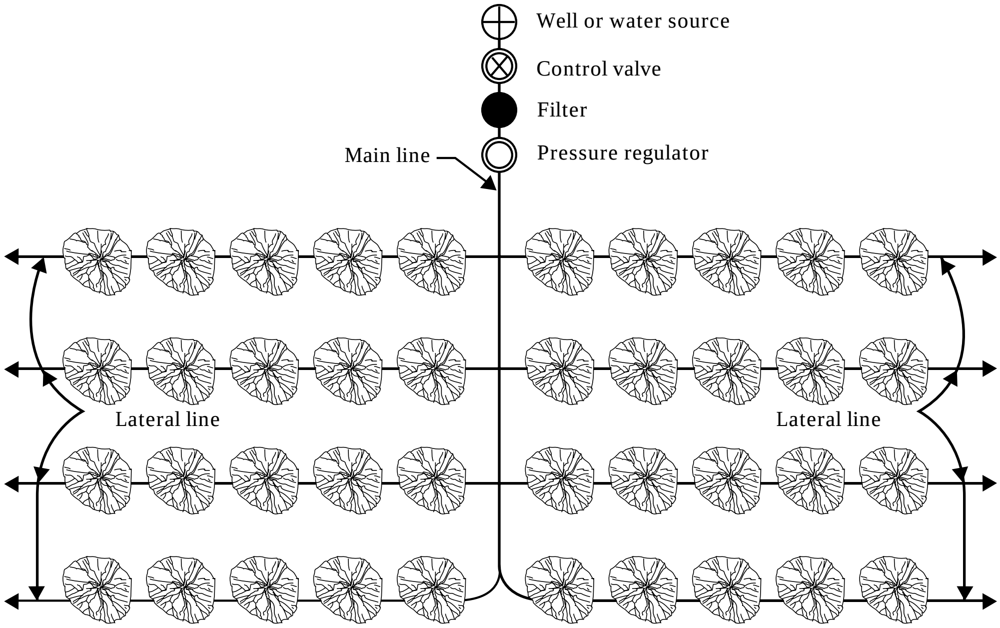
The system should be designed to last up to 5 years. Usually the distribution pipelines can be laid on the surface, although surface installations may make it difficult to use farm equipment for weed control. Potential rodent and wildlife damage should also be a consideration as to whether the distribution lines are on the surface or buried.

Once plants are established, water application should be timed to apply a larger quantity of water less frequently. This encourages deep rooting.

Augering a deep small diameter hole (post hole size) below each tree or shrub and backfilling the hole with local soil disrupts horizontal soil restrictions. This action helps move applied water deeper and encourages deep rooting.

In arid and semiarid areas, water application should be made in the spring as early as possible after the soil has thawed. This helps fill the entire soil profile to field capacity.

Figure 6–23 Typical windbreak layout



Discontinue water application in the fall before freezing temperatures. This helps ensure hardening off for winter. The lines should be drained.

To establish windbreaks in areas where precipitation can supply the needed water, irrigation needs to be discontinued after the plants are well established. This may require one or two summers of controlled tapering off. Less frequent applications of longer duration can encourage deeper root development.

Do not provide full irrigation to the plants. Use only the minimum amount of water necessary to produce healthy plant growth. Slower growth helps provide a stronger shrub or tree. Check soil moisture periodically with a hand probe. Once irrigation starts, plants should not be put into excessive stress for lack of moisture. Encourage rooting in nonirrigated areas by managing precipitation as a water source.

Micro irrigation systems used strictly for windbreak establishment require fewer emitters than systems used in mature stands. Emitters can be added as the shrubs and trees grow and mature, but the system must be designed to provide adequate capacity. The size of the laterals, submains, and mains should be designed to deliver adequate water to mature stands.

The following information is a guide to the number of emitters required in a medium to fine texture soil. Typically in coarse soils, it is better to use several low discharge emitters evenly spaced around the shrub or tree. On-time can be adjusted to provide the desired wetted depth and lateral water movement in the soil.

Low shrubs 2 to 3 feet tall	One or two 1-gph emitters	Placed 6 to 12 inches from base of plant.
Shrubs or trees to 5 feet tall	Two or three 1-gph emitters	Placed 12 inches from base of plant.
Shrubs or trees 5 to 10 feet tall	Three to four 1-gph emitters, or one or two 2-gph emitters	Equally spaced 2 to 3 feet from base of plant.
Trees >10 feet tall	Four to six 1-gph emitters, or two or three 2-gph emitters	Equally spaced about 4 to 8 feet from trunk. Generally, for a single tree, multiple emitters are better than fewer.

(i) Irrigating stream side (riparian) trees and shrubs

When supplying moisture to establish deep rooting trees in stream side riparian areas, point source micro irrigation emitters encourage deep rooting in layered coarse soils overlaying a water supply.

Using a power-pole sized auger (for trees), drill a hole at least 2 feet below the water table; then backfill hole with material removed. A post hole sized auger can be used for most shrubs. Backfill material will be free of horizontal soil layers caused by compaction and soil gradation (typically present in most water and wind deposited soils). Plant the tree or shrub near or in the hole, then locate an emitter at the top of the backfilled hole. Once the plant is established, irrigate with long duration, less frequent applications. Water will move down the disturbed soil profile. Developing roots will follow the irrigation water in the disturbed hole down to the water table. Long-term nonirrigated successful riparian vegetation (trees and shrubs) can be established 15 to 20 feet above a water source.

652.0604 Subirrigation systems

(a) General

Subirrigation is a water table management system that controls the elevation of a water table to provide water necessary for desired crop growth. A water table management system can lower an existing water table, maintain an existing water table, or raise a water table to a desirable elevation. A water table is generally held at a constant elevation during a crop growing season, but can be fluctuated. Water from a water table is supplied to plant roots by upward capillary water movement through the soil profile, also referred to as upflux. Water table is controlled by:

- Providing subsurface drainage to lower or maintain an existing water table, or by removing water from the soil profile using buried laterals.
- Providing controlled drainage by capturing rainfall to raise a water table to a desired elevation at or above the buried laterals.
- Introducing irrigation water via a buried lateral system to raise or maintain a water table at desired elevation at or above the buried laterals.

(1) Primary objectives of a water table management system

- Provide for trafficability of the soil surface for timely use of farm equipment.
- Reduce crop stress caused by excess water in the plant root zone.
- Reduce crop stress caused by deficiency of available soil moisture in the plant root zone.
- Provide a better root development environment in the soil.
- Minimize harmful offsite environmental pollution.
- Maximize use of rainfall.
- Minimize need for additional irrigation water.
- Control salinity.

(2) Advantages

- Permits storage of water in lower part of soil profile.
- Reduces need for pumping irrigation water for meeting crop water requirements.
- Can incorporate a subirrigation lateral system with a subsurface drainage lateral system with low additional cost.
- Reduces drainage pumping costs if required.
- Can be relatively easy to automate control of water levels in control structures.
- Captures plant nutrients at or near the water table for future use by plants.

(3) Disadvantages

- Labor intensive to manually adjust the elevation of weirs in water control structures to change from drainage mode to irrigation mode.
- Labor intensive to set and readjust automatic water level controlled mechanisms in water control structures. However, labor is minimal once they are adequately set.
- Total system costs can be relatively high in soils that have low hydraulic conductivity and are in high rainfall areas with undulating topography.
- Water quality must be high.
- In saline areas, an intensive salt content monitoring and management program is required to prevent excessive long-term upward movement and accumulation of damaging salts. Salt-tolerant crops can be effectively irrigated with saline water from a shallow water table, but where low salt-tolerant crops are included in the cropping rotation, downward movement of salts at some time may be required. The latter would require using excess irrigation water for leaching of salts, thus requiring free drainage. Offsite environmental pollution can occur where drainage effluent high in salts is allowed to enter surface water.

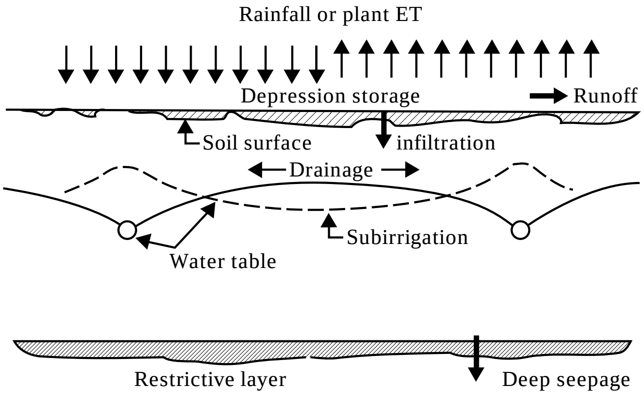
(b) Irrigation system components

A water table management system can consist of buried drainage or irrigation laterals, submains, mains, water table control structures, irrigation water intake structures, flow measuring devices, surface or buried irrigation water supply pipelines, a pumping plant, and power supply.

Buried laterals consist of a system of underground conduits generally spaced at uniform intervals. In the drainage mode, laterals discharge into a system of collectors or submains that outlet into mains. In the irrigation mode, flow is then reversed. Figure 6–24 displays a schematic of typical water management system with subsurface drainage laterals used for drainage or subirrigation. Separate systems for irrigation and drainage are encouraged for maximum efficiency.

The size, spacing, and depth of laterals are a function of soil hydraulic conductivity, desired elevation of water table in relation to ground surface (depth), available flow from soil mass to and from pipelines, available hydraulic gradient of laterals, and desirable time to reach a planned water table elevation. The size of submains and mains are a function of soil hydraulic conductivity and area served, lateral layout, discharge to and from laterals, and available hydraulic gradient of submains and mains.

Figure 6–24 Typical water table management system



Although separate subirrigation and drainage systems are more efficient, dual purpose systems are often used. Dual purpose systems generally require resetting slide gates and flashboards when changing from drainage to irrigation or irrigation to drainage modes; sometimes several times each growing season.

Each lateral (or group of laterals) requires a water table control structure in or near the submain. The water table control structure can be set manually or automatically to either allow free drainage or to establish a water table elevation upstream of the structure.

Irrigation intake structures are vertical pipes located in submains that simply allow input of irrigation water at the ground surface from an external water source. In the irrigation mode, water flows from the submains into the laterals and then out of the laterals into the soil. External water is supplied when rainfall does not maintain the desired water table elevation.

The most common pipe material for buried laterals is corrugated polyethylene plastic pipe (CPP). It can be installed either as perforated or nonperforated tubing preferably using laser grade controlled trenching and installation equipment.

(c) Planning and design considerations

(1) Controls

Water table elevation is commonly controlled by a manually adjusted weir for a group of laterals where submains discharge into the main. When excessive rainfall occurs, the water level in the control structure is lowered to allow free flow through the structure. This allows the drainage system to remove excess water more quickly.

The operator must decide when to raise or reset the weir to allow the water table to reestablish itself at the desirable height. If done too early the water table is held too high, and if done too late the water will have drained, thereby losing valuable water.

One solution is to provide an automatic water level control system. Float controlled valves can be used in place of the manually adjusted weir. When excessive rainfall events cause drainage outflow, the float mechanism opens a drain valve. As drainage outflow decreases, the float mechanism closes the drain valve as necessary. To maintain the water table at the desired elevation during periods of expected rainfall, it may be desirable to lower the controlled water table elevation 3 to 6 inches. This will increase available soil-water storage and allow the float controlled mechanism to discharge larger volumes of water during or immediately after heavy rainfall events.

(2) Upward water flow

Upward water flow (up flux) rate is a function of soil properties, primarily texture, and water table depth. Upward flow rate is generally most significant for medium textured soils where the hydraulic gradient and hydraulic conductivity together produce a usable rate of water supply.

Figure 6–25 displays water table contribution to meet irrigation requirements as a function of soil type and water table depth. For a sandy loam soil to meet a crop ET rate of 0.2 inch per day in a steady state upward flow condition, the water table needs to be held at about a 2-foot depth. However, with either clay or sand, the water table depth needs to be about 0.5 foot. Additional details are provided in NEH, Part 623 (Section 15), Chapter 2, Irrigation Water Requirements. Also refer to section 652.0605 for local data on soils versus upward flow rate characteristics.

(3) Installation

Installation of buried drainage pipe can be accomplished with a variety of equipment and labor including:

- Laser grade controlled trenching or plow-in equipment with continuous placement of CPP drainage tubing, with or without filter or envelope material.
- Laser or nonlaser controlled trenching equipment with hand installed CPP drainage tubing, clay or concrete tile, and semirigid perforated plastic or perforated steel pipe.
- Backhoe type equipment with hand installed CPP drainage tubing, clay or concrete tile, and semirigid perforated plastic or perforated steel pipe.

Most common buried drainage pipe is corrugated polyethylene plastic pipe (CPP) tubing. However, concrete and clay tile or perforated PVC plastic or steel pipe can be used. With concrete and clay tile, the joints are butted together with no gaskets. Protection is needed to prevent soil particle movement into the pipeline at the open joints. When water is introduced into a subsurface irrigation system (buried conduits), velocities through the perforations or joints are typically higher than those in the drainage mode. The higher velocities can dislodge soil particles that can then move into the conduit in the drainage mode. Depending on soil characteristics, flow rate and velocity, opening size, and configuration in the buried conduit, filters, and envelope material may be needed. See NEH, Section 16, Drainage, or the local drainage guide for additional details on filter and envelope design criteria.

(d) Design procedures

In many areas design procedures and criteria are based on local field experience. Retrofitting of existing subsurface drainage systems to water table management systems typically involves the installation of water table control structures. The area to be subirrigated will closely coincide with the area drained. To assure full field coverage, additional buried laterals may need to be installed for subirrigation laterals.

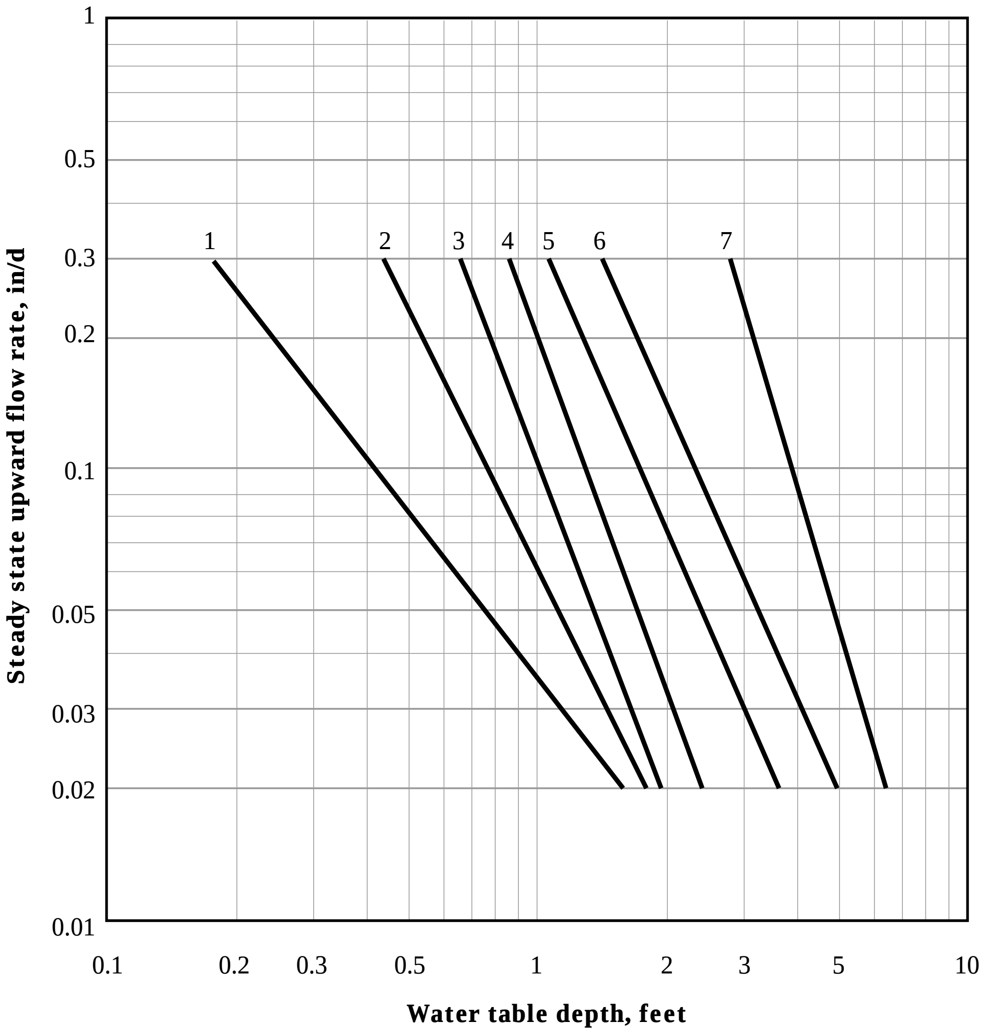
NRCS has supported the development of computer models to assist with planning, design, and operation of water table management systems. These models include DRAINMOD and SI-DESIGN.

(1) DRAINMOD

This computer model was developed by North Carolina State University (Richard “Wayne” Skaggs) with NRCS support. DRAINMOD is a simulation model that characterizes responses in a soil-water regime to various combinations of subsurface and surface water management operations. It can predict the response of a water table and soil water movement above a water table to rainfall, crop ET, various degrees of subsurface and surface drainage, and the use of water table control. It was originally intended for use mostly in humid areas, but can be used anywhere historical hourly rainfall data are available. Soil parameters for use in the model are developed by the computer program, DMSOILS.

Figure 6–25 Water table contribution to irrigation requirements as a function of water table depth and soil type

Soil type	Line number
Sticky clay	1
Loamy sand	2
Clay	3
Peat	4
Clay loam	5
Sandy loam	6
Fine sandy loam	7



(2) SI-DESIGN

This model was developed by Michigan State University (Harold "Bud" Belcher) with NRCS support. The objective of the model is to aid efficient design of water table management systems. It has modules for:

- Rainfall management—Calculates design rainfall amounts using historic growing season rainfall at desired frequency of occurrence.
- Investigating effect of buried lateral systems—Depth to lateral and to water table at midpoint between laterals, lateral diameter, hydraulic gradient of laterals, area effected (length and spacing).
- Assisting in determining the diameter of submains and mains.
- Evaluating the economic efficiency of production versus system components—Diameter, depth, and lateral spacing.

Specific locally approved design procedures and design examples are provided in section 652.0605.

652.0605 State supplement

Design procedures, tables, figures, charts, and design examples are presented using state approved procedures and computer programs. Complete procedures for planning and designing micro systems are in NEH, Part 623, (Section 15), Chapter 7, Trickle Irrigation. Supplier equipment catalogs and manufacturers' technical data are necessary for specific designs. Many types, shapes, and sizes of emitters, porous tubing, flexible PE plastic lateral tubing, and other accessories are commercially available.

WA652.0605 State Supplement

Irrigation System Design

Irrigation system design information is obtained from a number of software programs and guides. Information is available on the web (see Chapter 5, Section 652.0505) for a number of different sources. Other information is contained in NRCS references such as NEH Section 15. Section 15 has various chapters on different types of system.

This state supplement section includes some basic information which can be used to design irrigation systems with the above listed references material. The following tables and reference material include information that is not readily available.

Table WA6-1, titled "GPM/Acre Requirement to Meet Peak Consumptive Use Irrigating 24 hrs/day," should be used in order to calculate the acres that can be irrigated from the crop consumptive use amount (Chapter 4) and the efficiency of the system. The flow rate of the water supply must be adequate to meet peak crop consumptive use. The landowner may want to alter cropping patterns to more effectively utilize water supplies. For instance, planting the entire acreage to alfalfa would require a peak water use in July and August. Planting part of this acreage to winter wheat would move the peak use rate to the spring months. Normally, there would be a larger water supply available in the spring with a surface water source and the peak use in July and August could be reduced.

Another alternative would be to use a limited irrigation approach. Using the information in the Washington supplement (Chapter 3, Crops) of the National Irrigation Guide (NIG) to determine when to apply irrigation water when limited supplies are available will help to maximize production with a limited water supply.

These alternatives need to be evaluated in light of current market conditions. The objective is to maximize economic returns for the landowner, not necessarily to maximize crop production.

Use Table WA6-1 to obtain system flow rate (GPM/Acre) from the peak consumptive use rate and the system efficiency.

Irrigation application efficiencies are shown in Table WA6-2, for typical systems used in Washington. The average efficiency column would be considered normal for design.

Example:

A landowner has a flow of 1000 gpm. The peak consumptive use of the crop is 0.25 inch/day. How many acres can be irrigated with a furrow system at 50 percent irrigation efficiency irrigating 24 hours per day? From Table WA6-1, find 9.4 gpm/acre needed.

Acres = 1000 gpm / 9.4 gpm/acre
= 106 acres can be irrigated

How many acres can be irrigated with 65 percent efficiency? Again from Table WA6-1, find 7.3 gpm/acre.

Acres = 1000 gpm / 7.3 gpm/acre
= 137 acres can be irrigated

For a different number of irrigation hours per day than 24, the formula below the table must be used. An Excel workbook could be used to create tables similar to Table WA6-1 for other time increments.

For a system that is only operated for 15 hours per day at 50 percent efficiency, what is the gpm/acre to apply the 0.25 inches per day?

$$q = \frac{(453)x(d)x(A)}{(t) \text{ x } (E)} = \frac{(453) \text{ x } (0.25\text{in.}) \text{ x } (1.0 \text{ ac.})}{(15\text{hr.}) \text{ x } (0.50)}$$

q = 15.1gpm/acre

Where:
d = net application depth in inches
A = acres
T = time in hours
E = irrigation efficiency of the system

$$E = \frac{\text{net irrigation}}{\text{gross application}}$$

Table WA6-1 GPM/Acre Requirement to Meet Peak Consumptive Use Irrigating 24 hrs./day

Consumptive Use in Inches/Day

Irrigation Eff.	**0.15**	**0.16**	**0.17**	**0.18**	**0.19**	**0.20**	**0.21**	**0.22**	**0.23**	**0.24**	**0.25**	**0.26**	**0.27**
30%	9.4	10.1	10.7	11.3	12.0	12.6	13.2	13.8	14.5	15.1	15.7	16.4	17.0
40%	7.1	7.6	8.0	8.5	9.0	9.4	9.9	10.4	10.9	11.3	11.8	12.3	12.7
50%	5.7	6.0	6.4	6.8	7.2	7.6	7.9	8.3	8.7	9.1	9.4	9.8	10.2
60%	4.7	5.0	5.3	5.7	6.0	6.3	6.6	6.9	7.2	7.6	7.9	8.2	8.5
65%	4.4	4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.7	7.0	7.3	7.6	7.8
70%	4.0	4.3	4.6	4.9	5.1	5.4	5.7	5.9	6.2	6.5	6.7	7.0	7.3
75%	3.8	4.0	4.3	4.5	4.8	5.0	5.3	5.5	5.8	6.0	6.3	6.5	6.8
80%	3.5	3.8	4.0	4.2	4.5	4.7	5.0	5.2	5.4	5.7	5.9	6.1	6.4
85%	3.3	3.6	3.8	4.0	4.2	4.4	4.7	4.9	5.1	5.3	5.6	5.8	6.0
90%	3.1	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.5	5.7
95%	4.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.4

Consumptive Use in Inches/Day

Irrigation Eff.	**0.28**	**0.29**	**0.30**	**0.31**	**0.32**	**0.33**	**0.34**	**0.35**	**0.36**	**0.37**	**0.38**	**0.39**	**0.40**
30%	17.6	18.2	18.9	19.5	20.1	20.8	21.4	22.0	22.7	23.3	23.9	24.5	25.2
40%	13.2	13.7	14.2	14.6	15.1	15.6	16.0	16.5	17.0	17.5	17.9	18.4	18.9
50%	10.6	10.9	11.3	11.7	12.1	12.5	12.8	13.2	13.6	14.0	14.3	14.7	15.1
60%	8.8	9.1	9.4	9.8	10.1	10.4	10.7	11.0	11.3	11.6	12.0	12.3	12.6
65%	8.1	8.4	8.7	9.0	9.3	9.6	9.9	10.2	10.5	10.7	11.0	11.3	11.6
70%	7.6	7.8	8.1	8.4	8.6	8.9	9.2	9.4	9.7	10.0	10.2	10.5	10.8
75%	7.0	7.3	7.6	7.8	8.1	8.3	8.6	8.8	9.1	9.3	9.6	9.8	10.1
80%	6.6	6.8	7.1	7.3	7.6	7.8	8.0	8.3	8.5	8.7	9.0	9.2	9.4
85%	6.2	6.4	6.7	6.9	7.1	7.3	7.6	7.8	8.0	8.2	8.4	8.7	8.9
90%	5.9	6.1	6.3	6.5	6.7	6.9	7.1	7.3	7.6	7.8	8.0	8.2	8.4
95%	5.6	5.8	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.7	7.9

This table is based on the formula

$$Q = \frac{(453) \times (d) \times (A)}{(t) \times (E)}$$

where Q = gallons per minute irrigation flow rate
453 = conversion factor
d = net application depth in inches
A = acres
t = time in hours
E = irrigation efficiency of the system $= \frac{\text{net irrigation}}{\text{gross application}}$

Table WA6-2 Application efficiency range for various irrigation systems[1]

Type	Range	Avg (%)
Surface Irrigation		
Level Basin	80-95	85
Graded Border	50-80	65
Furrow or Corrugations	50-80	65
Surge	60-90	75
Micro Irrigation		
Point Source Emitter	70-95	88
Line Source Emitter	75-95	90
Spray Emitter	70-95	85
Sprinkler Irrigation		
Handline/Wheeline	60-85	75
Traveling Big Gun	55-75	65
Solid Set (Above Canopy)	60-75	60
Solid Set (Below Canopy)	70-85	75
Center Pivot		
Impact Sprinkler w/end gun	75-90	80
Drops, spray heads w/o end gun	75-95	85
Lateral Move		
Spray heads		
w/ hose feed	75-95	90
w/ canal feed	75-95	85

Wind and temperature can affect efficiency. For example – a 5/32” nozzle will loose 9% in winds of 5 mph and 80^0 F.
A 5/32” nozzle will loose about 20% if wind is 15 mph. The losses will reach 26% with 15 mph wind and temperatures of 100^0 F.[2]

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[1] IRRIGATION SYSTEM EFFICIENCIES,2002, Terry A. Howell, ARS, Bushland, TX
[2] Montana State Univ, Extension Service – Wind Effects on Irrigation Efficiency – Management Harder than it Sounds! Jim Bauder,

Polyacrylamide

Polyacrylamide (PAM) has been used for the past 15 years on surface irrigation fields to reduce erosion. The amount of sediment saved has been shown to be 96% of the non-PAM field. The following excerpt on polyacrylamide is from the Nebraska Extension Service[i]. This is included to show the benefit of PAM on soils, crops, and field configurations similar to those found in Central Washington.

Research was conducted at the Panhandle Research and Extension Center in Scottsbluff, Nebraska in 1996 and 1997. Furrow stream size was approximately 12 g.p.m. Field slope was 0.2 percent and field length was 1,000 feet. The soil was a Tripp, very fine sandy loam. The crop grown was dry beans in 30-inch rows with every other row irrigated. Furrow advance time to 1,000 feet and sediment loss (tons/acre) were measured and given in *Figures 1-3*.

In 1996, the three treatments were: 1) PAM; 2) no PAM; and 3) patch PAM. *Figures 1* and *2* show the results for three irrigations during the growing season. The patch PAM treatment was done by sprinkling PAM in the dry furrow before water was started. Advance time was similar for all treatments. The amount of soil loss was greatest for the no PAM treatment and the least for the PAM treatment. The patch PAM treatment, although providing some reduction in erosion, was not as effective as having the PAM mixed with the water prior to application.

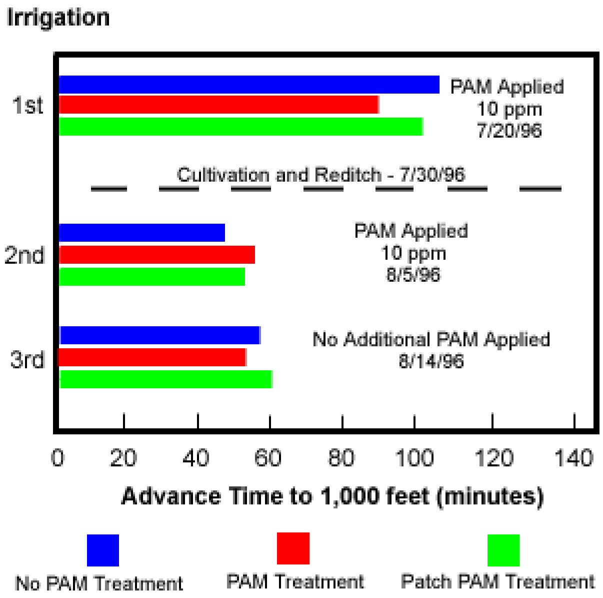

Figure WA6-1. Furrow advance time to 1,000 feet for each irrigation, treatment of no PAM, PAM and patch PAM (1996).

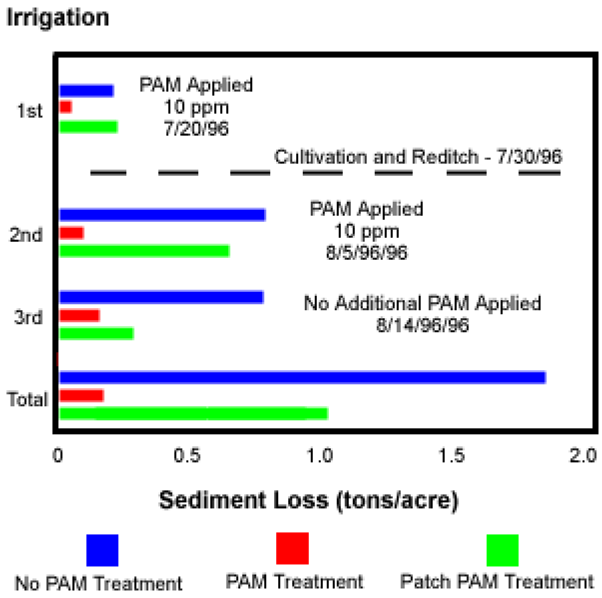

Figure WA6-2. Sediment loss (tons/acre) for each irrigation and total sediment loss (tons/acre) for treatments of no PAM, PAM and patch PAM (1996).

In 1997, four treatments were compared: 1) PAM; 2) no PAM; 3) surge irrigation with PAM; and 4) surge irrigation with no PAM. These results are shown in *Figure 4*. The advance time to 1,000 feet was similar for all four treatments during the three irrigations. However, the advance times for the treatments using surge irrigation were slightly below the advance times for the conventional irrigation treatments. Soil erosion was consistently less when PAM was mixed with the irrigation water.

If a producer is using surge and wants to try using PAM, particular attention should be paid to furrow advance time. Surge irrigation, through its wetting and drying process, tends to seal the surface of the soil and reduce intake rate. This, in turn, advances water down the field faster.

On many soils, PAM tends to increase soil intake rate by maintaining open pores on the soil surface. The result may be slower water advance times. Using polyacrylamide in irrigation water probably means water management strategies must change. For more information on making management changes to furrow irrigation systems, see NebGuide G97-1338, *Managing Furrow Irrigation Systems*.

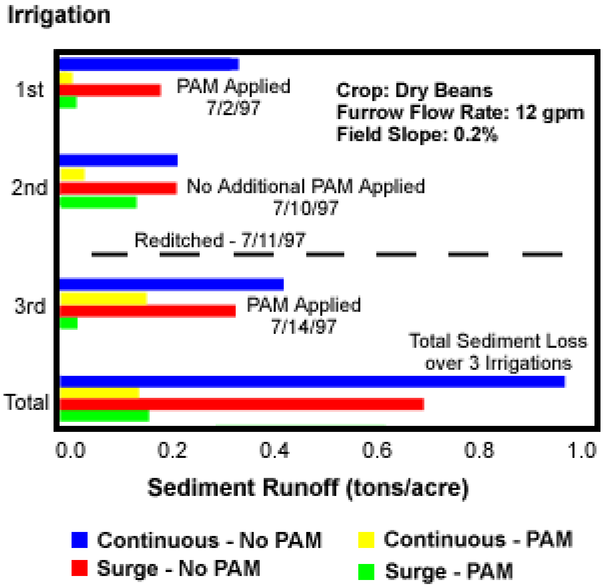

Figure WA6-3. Sediment loss (tons/acre) for each irrigation and total sediment loss (tons/acre) for treatments of no PAM – continuous irrigation, PAM – continuous irrigation, no PAM – surge irrigation and PAM – surge irrigation (1997).

Sprinkler Irrigation

Typical irrigation precipitation rates are given below. This is based on the following equation:

$$\text{Prec. Rate} = \frac{Nozzle - gpm * 96.3}{Spacing - ft}$$

Table WA6-3 Irrigation Precipitation Rate, inches per hour

Spacing - ft	**Discharge per Sprinkler - gpm**																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**15**	**20**	**25**	**30**	**40**	**50**	**60**	**70**	**80**
20x20	0.24	0.48	0.72	0.96	1.20	1.44	1.69	1.93	2.17	2.41										
20x30	0.16	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.61	1.93									
20x40	0.12	0.24	0.36	0.48	0.60	0.72	0.84	0.96	1.08	1.20	1.44	1.81								
20x50	0.10	0.19	0.29	0.39	0.48	0.58	0.67	0.77	0.87	0.96	1.16	1.44	1.93							
20x60	0.08	0.16	0.24	0.32	0.40	0.48	0.56	0.64	0.72	0.80	0.96	1.20	1.61	2.01						
25x25	0.15	0.31	0.46	0.62	0.77	0.92	1.08	1.23	1.39	1.54	1.85	2.31								
30x30	0.11	0.21	0.32	0.43	0.54	0.64	0.75	0.86	0.96	1.07	1.28	1.61	2.14							
30x40	0.08	0.16	0.24	0.32	0.40	0.48	0.56	0.64	0.72	0.80	0.96	1.20	1.61	2.01	2.41					
30x50		0.13	0.19	0.26	0.32	0.39	0.45	0.51	0.58	0.64	0.77	0.96	1.28	1.61	1.93					
30x60		0.11	0.16	0.21	0.27	0.32	0.37	0.43	0.48	0.54	0.64	0.80	1.07	1.34	1.61	2.14				
40x40		0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	0.60	0.72	0.90	1.20	1.50	1.81	2.41				
40x50		0.10	0.14	0.19	0.24	0.29	0.34	0.39	0.43	0.48	0.58	0.72	0.96	1.20	1.44	1.93				
40x60			0.12	0.16	0.20	0.24	0.28	0.32	0.36	0.40	0.48	0.60	0.80	1.00	1.20	1.61	2.01			
40x80			0.09	0.12	0.15	0.18	0.21	0.24	0.27	0.30	0.36	0.45	0.60	0.75	0.90	1.20	1.50	1.81	2.11	
50x50			0.12	0.15	0.19	0.23	0.27	0.31	0.35	0.39	0.46	0.58	0.77	0.96	1.16	1.54	1.93	2.31	2.70	
50x60			0.10	0.13	0.16	0.19	0.22	0.26	0.29	0.32	0.39	0.48	0.64	0.80	0.96	1.28	1.61	1.93	2.25	
50x70				0.11	0.14	0.17	0.19	0.22	0.25	0.28	0.33	0.41	0.55	0.69	0.83	1.10	1.38	1.65	1.93	2.20
50x80				0.10	0.12	0.14	0.17	0.19	0.22	0.24	0.29	0.36	0.48	0.60	0.72	0.96	1.20	1.44	1.69	1.93
60x60				0.11	0.13	0.16	0.19	0.21	0.24	0.27	0.32	0.40	0.54	0.67	0.80	1.07	1.34	1.61	1.87	2.14
60x70					0.11	0.14	0.16	0.18	0.21	0.23	0.28	0.34	0.46	0.57	0.69	0.92	1.15	1.38	1.61	1.83
60x80					0.10	0.12	0.14	0.16	0.18	0.20	0.24	0.30	0.40	0.50	0.60	0.80	1.00	1.20	1.40	1.61
70x70					0.10	0.12	0.14	0.16	0.18	0.20	0.24	0.29	0.39	0.49	0.59	0.79	0.98	1.18	1.38	1.57
70x80						0.10	0.12	0.14	0.15	0.17	0.21	0.26	0.34	0.43	0.52	0.69	0.86	1.03	1.20	1.38
70x90							0.11	0.12	0.14	0.15	0.18	0.23	0.31	0.38	0.46	0.61	0.76	0.92	1.07	1.22
80x80							0.11	0.12	0.14	0.15	0.18	0.23	0.30	0.38	0.45	0.60	0.75	0.90	1.05	1.20
80x90								0.11	0.12	0.13	0.16	0.20	0.27	0.33	0.40	0.54	0.67	0.80	0.94	1.07

Spacing - ft	Discharge per Sprinkler - gpm																			
	1	2	3	4	5	6	7	8	9	10	12	15	20	25	30	40	50	60	70	80
20x20	0.24	0.48	0.72	0.96	1.20	1.44	1.69	1.93	2.17	2.41										
20x30	0.16	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.61	1.93									
20x40	0.12	0.24	0.36	0.48	0.60	0.72	0.84	0.96	1.08	1.20	1.44	1.81								
20x50	0.10	0.19	0.29	0.39	0.48	0.58	0.67	0.77	0.87	0.96	1.16	1.44	1.93							
20x60	0.08	0.16	0.24	0.32	0.40	0.48	0.56	0.64	0.72	0.80	0.96	1.20	1.61	2.01						
25x25	0.15	0.31	0.46	0.62	0.77	0.92	1.08	1.23	1.39	1.54	1.85	2.31								
30x30	0.11	0.21	0.32	0.43	0.54	0.64	0.75	0.86	0.96	1.07	1.28	1.61	2.14							
30x40	0.08	0.16	0.24	0.32	0.40	0.48	0.56	0.64	0.72	0.80	0.96	1.20	1.61	2.01	2.41					
30x50		0.13	0.19	0.26	0.32	0.39	0.45	0.51	0.58	0.64	0.77	0.96	1.28	1.61	1.93					
30x60		0.11	0.16	0.21	0.27	0.32	0.37	0.43	0.48	0.54	0.64	0.80	1.07	1.34	1.61	2.14				
40x40		0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	0.60	0.72	0.90	1.20	1.50	1.81	2.41				
40x50		0.10	0.14	0.19	0.24	0.29	0.34	0.39	0.43	0.48	0.58	0.72	0.96	1.20	1.44	1.93				
40x60			0.12	0.16	0.20	0.24	0.28	0.32	0.36	0.40	0.48	0.60	0.80	1.00	1.20	1.61	2.01			
40x80			0.09	0.12	0.15	0.18	0.21	0.24	0.27	0.30	0.36	0.45	0.60	0.75	0.90	1.20	1.50	1.81	2.11	
50x50			0.12	0.15	0.19	0.23	0.27	0.31	0.35	0.39	0.46	0.58	0.77	0.96	1.16	1.54	1.93	2.31	2.70	
50x60			0.10	0.13	0.16	0.19	0.22	0.26	0.29	0.32	0.39	0.48	0.64	0.80	0.96	1.28	1.61	1.93	2.25	
50x70				0.11	0.14	0.17	0.19	0.22	0.25	0.28	0.33	0.41	0.55	0.69	0.83	1.10	1.38	1.65	1.93	2.20
50x80				0.10	0.12	0.14	0.17	0.19	0.22	0.24	0.29	0.36	0.48	0.60	0.72	0.96	1.20	1.44	1.69	1.93
60x60				0.11	0.13	0.16	0.19	0.21	0.24	0.27	0.32	0.40	0.54	0.67	0.80	1.07	1.34	1.61	1.87	2.14
60x70					0.11	0.14	0.16	0.18	0.21	0.23	0.28	0.34	0.46	0.57	0.69	0.92	1.15	1.38	1.61	1.83
60x80					0.10	0.12	0.14	0.16	0.18	0.20	0.24	0.30	0.40	0.50	0.60	0.80	1.00	1.20	1.40	1.61
70x70					0.10	0.12	0.14	0.16	0.18	0.20	0.24	0.29	0.39	0.49	0.59	0.79	0.98	1.18	1.38	1.57
70x80						0.10	0.12	0.14	0.15	0.17	0.21	0.26	0.34	0.43	0.52	0.69	0.86	1.03	1.20	1.38
70x90							0.11	0.12	0.14	0.15	0.18	0.23	0.31	0.38	0.46	0.61	0.76	0.92	1.07	1.22
80x80							0.11	0.12	0.14	0.15	0.18	0.23	0.30	0.38	0.45	0.60	0.75	0.90	1.05	1.20
80x90								0.11	0.12	0.13	0.16	0.20	0.27	0.33	0.40	0.54	0.67	0.80	0.94	1.07
80x100								0.10	0.11	0.12	0.14	0.18	0.24	0.30	0.36	0.48	0.60	0.72	0.84	0.96
100x100										0.10	0.12	0.14	0.19	0.24	0.29	0.39	0.48	0.58	0.67	0.77

80x100		0.10	0.11	0.12	0.14	0.18	0.24	0.30	0.36	0.48	0.60	0.72	0.84	0.96
100x100				0.10	0.12	0.14	0.19	0.24	0.29	0.39	0.48	0.58	0.67	0.77

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[i] G98-1356- **Polyacrylamide – A Method to Reduce Soil Erosion -** This NebGuide describes polyacrylamide, what it is, how it can be used to reduce soil erosion due to, irrigation and what water management changes must be considered. - C. Dean Yonts, Extension Irrigation Engineer, Brian Benham, Extension Water Management Engineer