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PENNSYLVANIA IRRIGATION GUIDE

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Acknowledgment

This 2018 Pennsylvania Irrigation Guide is a rewrite of the 1972 version. It has been formatted for compatibility with the NRCS National Engineering Handbook, Part 652, Irrigation Guide. This update was prepared by Dr. Albert Jarrett, PE, Emeritus Professor of Agricultural Engineering, The Pennsylvania State University and W. Hosea Latshaw PE, Retired State Conservation Engineer, Pennsylvania.

This guide contains updated versions of the crop, soils, and water needs following those provided in the 1972 version of this guide. In addition, this Guide also provides guidance on how to design sprinkler and drip irrigation systems along with examples to demonstrate each of the steps in each design process.

Cover Photos from NRCS files.

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Symbols and Abbreviations

Listed below are most of the symbols and abbreviations contained in this Irrigation Guide. With each abbreviation are the word(s) it represents (Meanings) and the section within the Guide where the term was first used and defined.

Abbr.	Meaning	Section Where Defined
ΔZ	$Z_m - Z_e$ (ft)	Chap. 6, section (c.8.c)
ΔSW	Change in Soil-Water Content (in)	Chap. 9, section (c)
π	Pi (3.14)	Chap. 6, section (c.6.a.4)
φ	Portion of Circle receiving water (degrees)	Chap. 6, section (d.5.b)
%S	Percent Spacing (%)	Chap. 6, section (c.4.c)
A	Area (ft^2)	Chap. 6, section (c.2)
A_r	Application Rate (in/hr.)	Chap. 2, section (c)
A_w	Water applied (in)	Chap. 9, section (c)
AWC	Available Water Capacity (in)	Chap. 2, section (a)
AWC_{RZ}	Available Water Cap. effective root depth (in)	Chap. 6, section (c.1)
C_f	Correction Factor, f (# of outlets per lateral)	Chap. 6, section (c.8.c)
D	Pipe diameter	Chap. 6, section (c.6.a.4)
D_a	Application Depth (in)	Chap. 6, section (d.5.b)
D_d	Depth of water to apply (in)	Chap. 6, section (e.5)
DD	Design Depth (in)	Chap. 6, section (c.1)
DEP	Department of Environmental Protection	Chap. 1, section (c)
D_p	Deep Percolation (in)	Chap. 9, section (c)
E_c	Connection Efficiency (decimals)	Chap. 6, section (c.11)
E_m	Power Unit Efficiency (decimals)	Chap. 6, section (c.11)
E_p	Pump Efficiency (decimals)	Chap. 6, section (c.11)
E_t	Total Efficiency of the pump system (decimals	Chap. 6, section (c.11)
ET	Crop Evapotranspiration (in/day)	Chap. 4, section (b)
F_c	Friction Factor (psi/100 ft)	Chap. 6, section (c.6.a.4)
F_{cd}	Max. Permissible Friction Factor (psi/100 ft)	Chap. 6. Section (c.8.c)
g	Gravity (ft/sec^2)	Chap. 2, section (b.2)
GW	Groundwater flow (in)	Chap. 9, section (c)
h	Soil Tension (in)	Chap. 2, section (b.2)
H	Total Energy (in)	Chap. 2, section (b.2)
H_a	Time/day when grower is willing to irrigate (hr.)	Chap. 6, section (c.2)
H_L	Headloss or Friction (ft/100 ft) or (psi/100 ft)	Chap. 6, section (c.6.a.4)
H_T	Energy input from a pump (ft)	Chap. 6. Section (c.6.a)
I	Infiltration Rate (in/hr.)	Chap. 2, section (b.2)
I.D.	Inside Diameter (in)	Appendix B
II	Irrigation Interval (days)	Chap. 6, section (c.1)
IWRpm	NRCS Irrigation Water Requirement Software	Appendix A
K	Hydraulic Conductivity (in/hr.)	Chap. 2, section (b.2)
Kc	Crop Coefficient	Chap. 4, section (b)

Abbr.	Meaning	Section Where Defined
L	Spacing between laterals (ft)	Chap. 6, section (c.3)
L	Length of a section of pipe (ft)	Chap. 6, section (c.8.d)
L	Length of a Center Pivot Lateral (ft)	Chap. 6, section (d.5.b)
MAD	Management Available Depletion	Chap. 2, section (a)
NPSHR	Net Positive Suction Head Required (ft)	Chap. 6, section (c.10)
p	Pressure (psi)	Chap. 6, section (c)
P	Total Precipitation (in)	Chap. 9, section (c)
P_e	Pressure at the remote end of a lateral (psi)	Chap. 6, section (c.8.c)
P_m	Pressure at the main end of a lateral (psi)	Chap. 6, section (c.8.c)
PE	Polyethylene	Chap. 6, section (c.7)
PVC	Polyvinylchloride	Chap. 6, section (c.7)
Q	Flow Rate (gpm)	Chap. 6, section (c.4.d.1)
r	Radius of the last sprinkler (ft)	Chap. 6, section (d.5.b)
R	Sprinkler Radius (ft)	Chap. 6, section (d.5.b)
RO	Surface Runoff (in)	Chap. 9, section (c)
S	Spacing between sprinklers (ft)	Chap. 6, section (c.4.c)
S_d	Sets per day	Chap. 6, section (c.2)
SDL	Spray, Drift, and Canopy Interception (in)	Chap. 9, section (c)
SH_{max}	Maximum Suction Head (ft)	Chap. 6, section (c.10)
S_p	Traveler Speed (ft/min)	Chap. 6, section (d.3.a)
S_w	Sets per cycle	Chap. 6, section (c.2)
SRBC	Susquehanna River Basin Commission	Chap. 1, section (c)
T	Time (hrs.)	Chap. 6, section (d.5.b)
TDS	Total Dissolved Solids (ppm)	Chap. 6, section (e.3.b)
T_e	Total Energy (ft)	Chap. 6. Section (c.6.a)
T_s	Time per set	Chap. 6, section (c.2)
V	Velocity (fps)	Chap. 6, section (c.6.a.3)
WAE	Water Application Efficiency	Chap. 6, section (c.1)
W_d	Sprinkler Wetted Diameter (ft)	Chap. 6, section (d.1.b.1)
WD	Wetted diameter (ft)	Chap. 6, section (c.3)
Z	Elevation (ft)	Chap. 6, section (c.6.a)

Chapter 1 Introduction -- 652.0106 PA State Supplement

(a) General Information

The 2018 Pennsylvania supplement to the National Engineering Handbook (NEH), Part 652, Irrigation Guide, has been adapted from the earlier 1972 Pennsylvania Irrigation Guide. The material was developed to assist Pennsylvania NRCS field personnel and others working with Pennsylvania irrigators to provide general planning, design, and management guidance on various methods of irrigation commonly used in the State. Irrigation is the application of water. Agricultural irrigation, as applied, used, and managed in Pennsylvania is the application of water to a cropped area to supplement natural precipitation with the goal of optimizing quantity and quality of the harvested product. In addition, irrigation, especially sprinkler irrigation, has been used extensively as an economical method of (a) applying secondary treated wastewater to agricultural and forested lands to provide tertiary treatment of the wastewater, and (b) to apply liquid animal wastes to agricultural lands.

The Pennsylvania Irrigation Guide includes information and experience about soils, climate, water supplies, crops, cultural practices, and farming conditions in Pennsylvania. These basic factors must be evaluated in planning, design, and management of all irrigation systems.

(b) The Need for Irrigation

In Pennsylvania, annual precipitation averages about 40 inches distributed nearly uniformly across each of the 12 months averaging between 3.0 to 3.5 inches per month. There is, however, a very high degree of variability from week to week, month to month and year to year.

The water needed by most crops for evapotranspiration (ET), during their growing period, from planting to harvest, can be estimated by multiplying the portion of canopy cover times the design ET rate for Pennsylvania of 0.20 inches/day. For example, a crop with a full canopy cover will need 0.20 inches/day of water, or about 6.0 inches of water per month during the peak growing month. Most crops can benefit from some irrigated water to supplement natural precipitation. Growers of high-value crops often consider irrigation to supplement natural precipitation as insurance against reduced quantity and quality of yield during periods when rainfall is below normal.

(c) Can Irrigation Work for Me?

Successful irrigation in Pennsylvania requires careful attention to three areas; (1) the crop should be of great enough value to pay for the capital investment of an irrigation system, (2) the land owner must have access to and legal right to a sufficient water supply, and (3) the irrigation operator must have the time, skills and willingness to invest in the proper management of the irrigation system.

In Pennsylvania, a producer’s decision to invest in irrigation is often made based on the producer’s desire to guarantee that the produce being grown will be of high quality and ready for market when desired. Thus, the irrigation system becomes an insurance policy against poor quality produce and less than adequate produce ready for market in a timely manner.

Irrigation is by definition, a large consumer of water. Applying one inch of irrigation water to one acre of land requires the pumping and distribution of 27,000 gallons of water. When irrigating 10 acres of a full canopy crop during a period of little or no natural rainfall, there will be a need to pump and distribute 400,000 gallons of water per week. In Pennsylvania, irrigated water is considered to be consumptively used water. Therefore, irrigators using greater than 10,000 gallons of water per day will need a permit from PA-Department of Environmental Protection (DEP) and those within the Susquehanna River Basin using greater than 3 million gallons per month will need a permit from the Susquehanna River Basin Commission (SRBC). SRBC does not charge agricultural producers for consumptively used water, but they do require a permit. The Delaware River Basin Commission also requires a permit for major withdraws.

For most irrigators, learning to efficiently manage an irrigation system can be a time-consuming effort. Keeping track of rainfall and estimating crop water needs on a daily or weekly basis will require dedication and the willingness to learn many new concepts.

(d) An Irrigation System Plan
For an irrigation system to be successful, it must be planned to fit the site characteristics of soil, crop, climate, and water availability, plus the management requirements for irrigation.

This Guide is designed to assist potential irrigators, planners, and designers with the development and implementation of effective irrigation design and management plans. Soil characteristics related to irrigating agricultural crops are provided in Chapter 2. Crop effective rooting depths are given in Chapter 3. Growing seasons and the depth of water needed to grow most irrigated Pennsylvania crops, as well as the maximum amount of water that may be needed for irrigating these crops is provided in Chapter 4. Most of the irrigation systems used by growers in Pennsylvania are described in Chapter 5. Chapter 6 walks the designer through the irrigation system design process for those systems commonly used by producers in Pennsylvania. Finally, Chapter 9 was developed to help growers efficiently manage their irrigation system on a day by day or week to week basis.

The soil and crop water data are provided in this Guide to help the potential irrigators, planners, designers, and growers understand how to get the most out of their irrigation investment. The irrigation system design process is also provided, along with design charts and examples so those assisting the grower with system designs can use this Guide as their design guide.

(e) The Design Process
For those seeking to more fully understand how the various design decisions should be made, the following overview of the irrigation design process is provided. The logic and design criteria, along with design charts, equations, are included throughout this Guide. Extensive design examples are provided in the Appendices D, E, and F.

The recommended steps to follow in designing a sprinkler irrigations system are:

Step 1. Decide what crops the grower wishes to irrigate and in what fields these crops will be grown. The dimensions of each field and the slopes and relative elevations of each field will be needed. A scaled sketch of the fields and their relationship to the proposed water supply is highly desirable.

Step 2. Investigate and confirm the availability of an adequate water supply. Data and procedures in Chapter 4 will help the grower and designer determine how much water may be needed for irrigation of the desired crops.

Step 3. Establish the global parameters for the crop(s) to be irrigated and the soils where this(ese) crops will be grown. The two parameters that should be used as a starting point in the design are the design depth (DD) and irrigation interval (II) developed and explained in Chapter 6.

Step 4. Select the water distribution method to be used.

Step 5. Develop the overall, system wide management decisions based on the crop, the soil, and the desires of the irrigator.

Step 6. Select the sprinkler spacing; distance between laterals and distance between sprinklers on each lateral.

Step 7. Select the exact sprinkler to be used.

Step 8. On a scaled drawing of the field(s), with elevations of key locations known, layout where the laterals and sprinklers will be located. Also include on the field map, the proposed location of the pump, suction line and main.

Step 9. Properly size the laterals.

Step 10. Properly size the main transmission pipelines and the suction line if necessary.

Step 11. Determine the pump requirements for the most critical location in the field(s); usually the highest elevation.

Step 12. Select a pump and power unit to provide energy to water being pumped to the irrigation system.

Step 13. Within the decisions already made, learn how to properly decide when and how much water needs to be applied through the irrigation system. This is covered in Chapter 9.

Chapter 2 Soils -- 652.0204 PA State Supplement

A basic understanding of soil and soil-water relationships is necessary to properly plan, design, and operate any type of irrigation system.

The two most important soil characteristics that must be understood and known before an irrigation system can be planned, designed, or managed are:

(1) The water holding capacity of the soil within the effective rooting depth of the mature crop to be irrigated, and
(2) The maximum water intake rate of the soil.

(a) Soil-Water Relationships
Soil water exists as a film on the surface of soil particles. The thickness of this water film is associated with the water content of a soil and is related to the soil tension forces. The soil tension is the attractive force within the soil that seeks to be satisfied by filling the soil pores with water. This is the same phenomenon that causes the water on a wet surface to be absorbed by a towel. Soil tension is typically expressed as the height of a water column that can be attracted to or sucked into the soil. The concept of soil tension will be further developed later.

Usually soil consists of about 48 percent, by volume, solid mineral particles and about 2 percent organic matter. The remaining 50 percent is the pore space that is occupied by air and/or water in varying proportions. In this aerated environment, plant roots can extract the water and nutrients necessary for growth. An optimal balance of water, nutrients, and air produces high yields of agricultural crops.

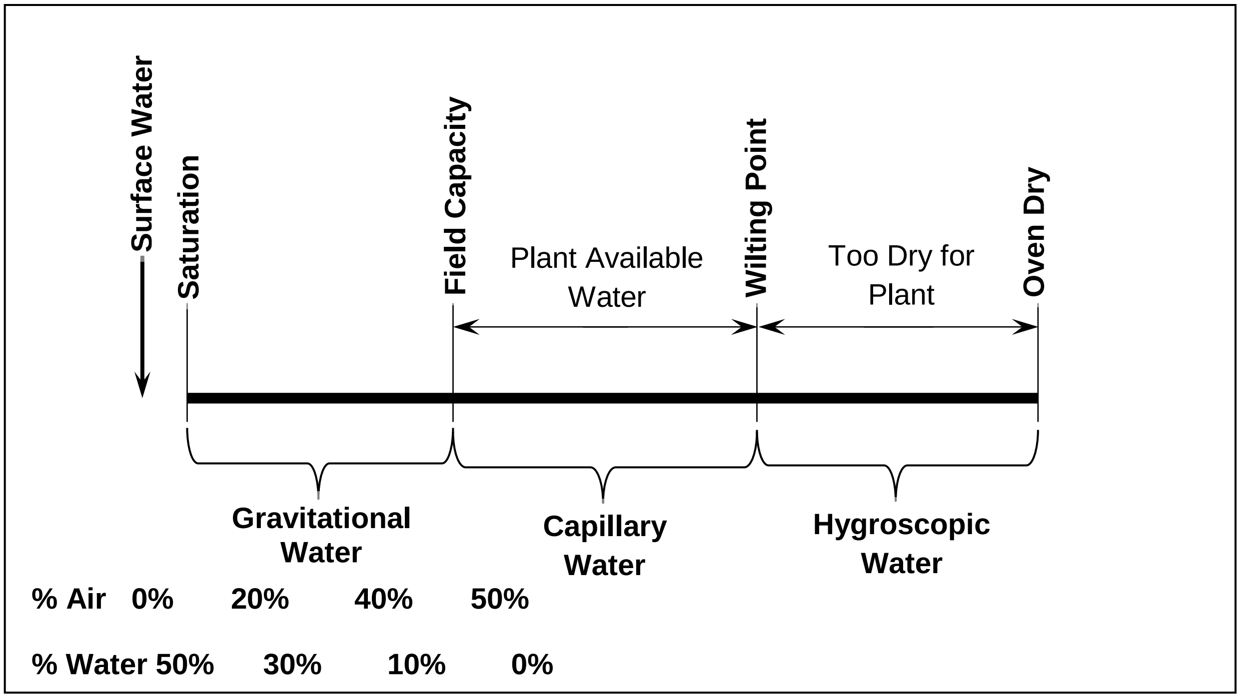
Figure 2.1 is one way of representing the pore space within a soil, called a soil-water continuum. The right end of the soil-water continuum represents an oven-dried soil. An oven-dried soil contains no water; all of the pore spaces are filled with air.

The left end of the continuum represents a saturated soil. At saturation, all of the air in the soil has been displaced by water so that 100 percent of the pore spaces are filled with water and no air is present. Between the ends of the continuum all combinations of water-to-air ratios can exist.

Two additional points of interest on the continuum to irrigators are the wilting point and field capacity. The **wilting point** is when the soil is too dry to support plant growth. The exact percentage of water in the soil at the wilting point varies from soil to soil and plant to plant but is generally estimated at 15 bars or atmospheres.

Field capacity is the soil-water content that occurs when water, under the influence of gravity, no longer drains from a soil, see Figure 2.1. A body of soil left to drain for a period of one to two days following a rainfall or wetting event, will give up the water from its larger pore spaces under the influence of gravity. By the end of one to two days of drainage, the losses of water by gravity will slow and eventually stop. When gravity can no longer remove water from the soil, the soil has reached field capacity.

Figure 2.1 Soil-Water Continuum



Soil water existing in each of the regions of the continuum includes:

1. **Hygroscopic** water is water held in a thin film by the molecular attraction of the colloidal particles in the soil. This form of water is essential for a soil to exist as a soil, but hygroscopic water is held to the soil particles so tightly that it cannot be used by plants. Hygroscopic water can be driven out of a soil only by evaporation, usually only with the application of heat.

2. **Capillary** water is water held in the pore spaces between the soil particles and is held against the force of gravity by the surface tension of the water. Capillary water is another name for the water in a soil between field capacity and the wilting point. Capillary water is the main source of water for plants. This was referred to as available water capacity (AWC) in Chapter 1.

3. **Gravitational** water occupies the larger pore spaces and can be removed from a soil by gravity. It is this form of water that quickly passes through the soil having the capability to leach plant nutrients and refreshing the local water table. Gravitational water occupies the same pore spaces that must be filled with air if healthy agricultural, aerobic plants are expected to grow.

4. **Runoff or Standing Water** is water in quantities greater than can be taken into the soil in a timely manner. This excess water will remain on the soil surface and will exist as standing water or as flowing (**runoff**) water. If allowed to flow unchecked over the soil surface it may initiate erosion.

Plants grown as the major part of cropland agriculture to produce food and fiber require an aerobic environment (where free oxygen is available in the soil's pore spaces). Consequently, soils that are to be used for production agriculture must have the large pores drained by gravity, so air is present and available in the root zones of the crops. When land areas are wet or saturated much of the time agricultural vegetation, which require free oxygen, give way to hydrophytes that can grow in saturated, anaerobic soils. Few agricultural crops are hydrophytes. Successful irrigation for crop production requires an irrigator to properly manage the amount of water stored in the soil from the soil surface to the depth of the crop root penetration. In other words, irrigation is used as a tool to manage the water in the root-zone soil between wilting point and field capacity. If the water content of the root-zone soil decreases below the wilting point, the crop will stop growing and, in some cases die. If the water content in the root-zone soil increases above field capacity, the air content of the soil will decline to the point where the plants will no longer grow properly. In addition, any water applied to the root-zone soil that brings the water content above field capacity will drain below the root zone and be lost to the crop (wasted energy, wasted water, if the water was applied by an irrigation system).

Soil Tension — When a soil is saturated, the soil no longer tries to attract water into its pores; they are full. As the water content of the soil pores decrease, the soil develops an increasing desire to take in more water. In essence, a contest develops between the soil trying to attract more water and the plant roots, residing in the soil pores, trying to absorb this same water from the soil pores. As the root-zone water content declines towards the wilting point, the plant must work harder and harder to get the water it needs. And, when the root-zone water content reaches the wilting point, the soil is holding its remaining water so tightly that the plant can no longer get enough water and the plant dies.

Therefore, the soil acts as a reservoir, and its water must be replenished often enough to keep water available for the plant's withdrawal as required for optimum growth and production.

This leaves an important question. At what point, between field capacity and the wilting point, does a plant begin to be stressed to the point where the quantity and quality of its product begins to suffer? This point is referred to as the Management Allowed Depletion (MAD). Historically, irrigators have assumed that the MAD is when 50% of the AWC has been used by the plant. Simple logic might lead an irrigator to try to keep the root-zone soil closer to field capacity. Sprinkler systems are usually managed to keep the root-zone soil in the wetter half of the AWC. Microirrigation (drip) systems are often managed to keep the root-zone water closer to field capacity. Depending on the type of irrigation, the crop being irrigated, and the availability of irrigation water, MAD can range from 30 to 60%. Fifty percent is the normal recommended MAD value for most irrigated Pennsylvania crops. Crop specific recommended MAD values can be found in NEH 652 Table 3-3.

The AWC for all Pennsylvania soil series are shown in Table 2.1 for the effective rooting depths of 6, 12, 18, and 24 inches. Some crops have roots that penetrate deeper than 24 inches. When designing and managing an irrigation system the focus should be on the portion of the root zone where the majority of the roots are located, called the **effective root depth**. This usually is the top 50 to 60% of the total rooting depth. Managing the AWC within the effective root depth is most important.

(b) Water Intake Rate

The goal of irrigation is to apply water to the soil at a rate that will allow all of the applied water to enter the soil profile and come to reside in the effective rooting zone of the crop. If irrigation is to be successful, the water applied to a soil, for growing a crop, must be applied at a rate that is slow enough so that **ALL** of the applied water enters the soil at the location it is applied. This raises the question "How fast will a soil take water into its profile?" The study of the rate at which water will enter a soil has led to the emergence of a number of soil-based parameters all of which are an attempt to quantify this "water intake rate" parameter. These parameters may be referred to as (a) "water intake rate", (b) "infiltration rate", (c) "permeability", or (d) "saturated hydraulic conductivity" depending on the background of the person and desires of the organization for which the person works. Technically, these terms are not exactly identical, but as we define each term, it will be understood how each has come to be found in the irrigation lexicon.

(b.1) Water Intake Rate

Water Intake Rate is a generic term that means just what it says; "It refers to the rate at which water applied to the soil surface, by natural precipitation or irrigation, will enter the soil."

(b.2) Infiltration Rate

Infiltration rate in the context of soils is "the rate at which free water located, at or on, the soil surface will enter the soil profile." Because there are two sources of energy present that cause water to move downward into the soil profile, the infiltration rate is not always constant. The slowing of the infiltration rate (see Figure 2.2) can be understood by Darcy's Law. Darcy's Law is a formula that relates the rate of water movement into a soil to the energy sources causing the water to move into the soil. In its simplest form Darcy's Law can be written as:

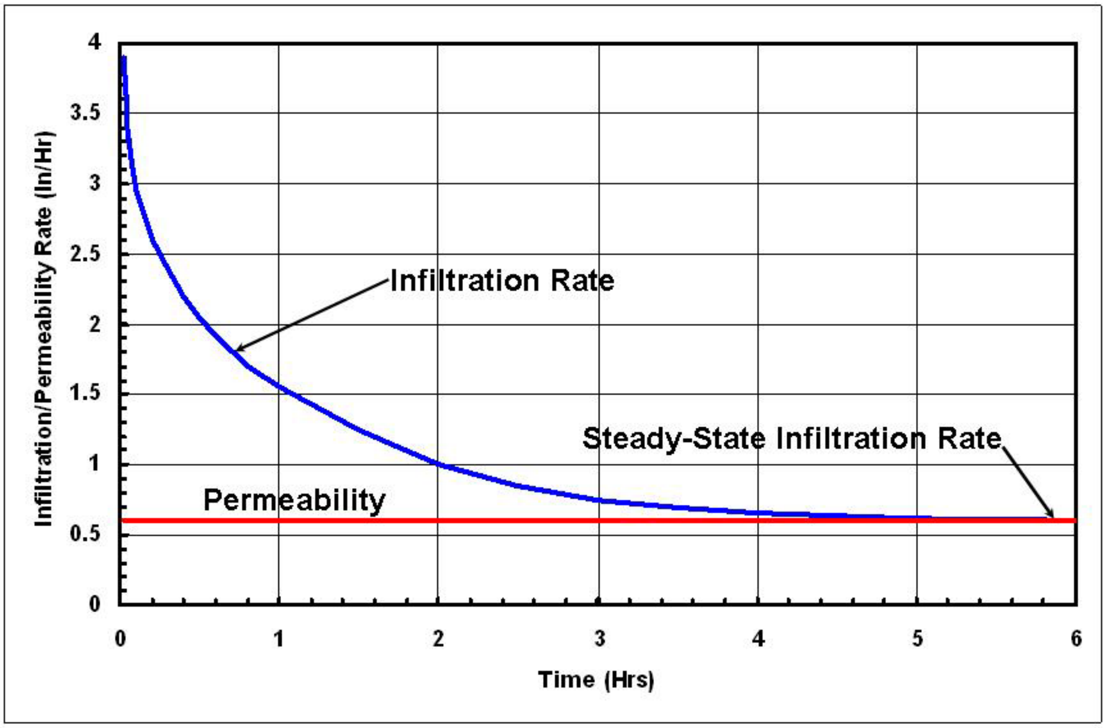
$$I = -K \frac{\Delta H}{\Delta Z} \tag{2.1}$$

K is the hydraulic conductivity of the soil. This is the same parameter discussed below called the saturated hydraulic conductivity, K_{sat} when the soil is saturated. The resulting I is the infiltration rate or velocity at which the water actually moves into the soil and ΔH/ΔZ is a term often called the gradient. In a saturated soil where the water is moving vertically downward, the gradient is one (1). Under saturated vertical-flow conditions the velocity at which water moves through the soil is equal to K_{sat}. If K_{sat} is 3 in/hr, the water will move into the soil at a rate of 3 in/hr.

Looking a little deeper into the ΔH/ΔZ term, the "H" term, is the total energy moving the water into the soil. The total energy H is the sum of two energy values; (i) is a term called the soil tension, h, which is a measure of energy the soil provides because the soil desires to fill its pores with water. When the soil is saturated, h is zero; the soil no longer desires to take in any more water. As the soil gets dryer, the h value increases. This means that as the soil dries, the soil becomes more desirous to fill its pores with water. Therefore, as a soil dries, the soil's desire for water increases greatly. The other energy source causing water to flow into the soil is (ii) gravity, g. The total energy causing water to flow into a soil (infiltrate) is: H = h + g.

As can be seen in Figure 2.2, the infiltration process starts at a very fast rate. In very dry soils this initial infiltration rate can be shown to be infinite because the soil tension energy, h attempting to draw water into the soil is extremely large. Under dry conditions, this soil tension energy far exceeds the influence of gravity.

Figure 2.2 The Infiltration Relationship



ΔZ, or Z, is the wetted depth (or front) in the soil. At the start of an infiltration event, the wetted front has not started yet, Z = 0. As water enters the soil, it is stored in the wetted front, which slowly gets deeper, so Z increases. At the beginning of the infiltration process, the rate at which water moves into the soil starts very fast and slows as time move forward.

During the latter portion of the infiltration process, the rate at which water enters the soil continues to decline and approaches a steady-state or constant intake rate. This constant infiltration rate is also the maximum intake rate for water applied to the soil by irrigation or precipitation. At times, this constant infiltration rate is also called the permeability or the saturated hydraulic conductivity.

(b.3) Permeability
Permeability is the term used to refer to the soil-water flow rate when the soil has become saturated (all the pores are filled with water). Permeability is most commonly used in the earth sciences and engineering.

(b.4) Saturated Hydraulic Conductivity
The soil science and soil physics professions call the flow rate when the soil is saturated the saturated hydraulic conductivity. Permeability and saturated hydraulic conductivity are two names for the same property.

(b.5) Maximum Intake Rate for Irrigation
In Table 2.1 guidance is given for the maximum intake rate for each Pennsylvania soil series. It is important that the irrigation system never applies water to the soil at a rate that will cause ponding, runoff leading to soil erosion, or surface loss of irrigation water. Table 2.1 refers to the maximum intake rate, which is another way of describing the permeability or saturated hydraulic conductivity of the soil. This rate from Table 2.1 should not be exceeded unless local knowledge is available to indicate that otherwise will not cause runoff.

Based on the previous discussion, it could be assumed that the permeability or the saturated hydraulic conductivity of a soil is a constant. The maximum intake rate of a soil is generally based on the actual soil texture of the soil and soil textures are known to vary among soils labeled with the same soil series. Table 2.1 simplistically indicates that each soil series has a fixed, measurable permeability or saturated hydraulic conductivity. In the practical world almost, anything and everything done to a soil may, and probably will, change the rate at which rain or irrigated water will enter and flow through the soil. The following changes generally increase a soil's water intake rate:

- When tilling the soil, the soil's bulk density decreases and the short-term rate at which water will flow through the soil increases.
- After applying manure to or incorporating crop residue into the soil, the long-term aggregation process will be enhanced and the rate water flows through the soil will most likely increase.
- When growing a crop, as the plant roots develop and invade and pervade the rooting zone, the rate water flows through the soil may increase.
- As the structure within a soil develops and becomes more stable, the rate water will move through the soil increases.
- Residue left on or applied to the soil surface will protect the soil and enhance the soil's ability to take in water.
- When soil is frozen, the expanded soil-water will enlarge the soil pores and increase the rate at which the soil will take in water after the frost has melted.
- When a grower adopts no-till, the water intake rate will stabilize and remain at a high rate.

The following changes generally decrease a soil's water intake rate:

- As water, from rain or irrigation, flows through the soil during the growing season the density of the soil increases as the soil re-consolidates and the rate water will move through the soil decreases.
- When driving over or walking on a soil, the soil is compacted. The wetter the soil, the easier it is to compact the soil. Water moves slower through compacted soil than through non-compacted soil.

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- As the percentage of clay in a soil's texture increases the rate water will move through the soil decreases.
- Rain or irrigation droplets hitting bare soil breakdown the soil's surface aggregates and puddle the soil causing a slowly permeable skin that will greatly decrease the soil's ability to take in water.

Because irrigation systems should never apply water to the soil at a rate that causes runoff or erosion, guidance is provided about how fast each Pennsylvania soil will infiltrate water. It is recommended that reliable local sources be consulted to determine water intake rates for the soils being irrigated. The positive side of this discussion is that seldom should an irrigation system be designed to apply water at or even near the maximum water intake rate for the soil as shown in Table 2.1. Additional discussion will be provided in Chapter 6.

(c) Note about Irrigation Application Rates
There are two ways the term "application rate" is used in irrigation.

The first, and most useful, is the depth of water applied divided by the time period the water is being applied. Example: 1.2 inches of water is applied during a 5-hour irrigation set. The application rate is 1.2/5 = 0.24 inches/hour.

The second is what is sometimes called the "instantaneous application rate". The instantaneous application rate is a measure of the application rate measured only when the irrigation water is being applied to a specific location. Example: A center pivot system applies 2.1 inches of water during one 12-hour rotation around a field. However, the 2.1 inches of water is applied to a specific location (imagine a catch can setting in this field) within the field for only 20 minutes. Therefore, this instantaneous application rate is 2.1/0.33 = 6.4 inches/hour. While the total fields average application rate is 2.1/12 = 0.175 inches/hour. These high instantaneous application rates are a by-product of the geometry of center pivots and can cause localized runoff when soils have limited intake rates.

(d) Information for Design Purposes
Table 2.1 contains information on maximum application/intake rates, and available water capacity for Pennsylvania soils.

Column (1) - Soil Series – This column shows the soils series name.

Column (2) - Maximum Intake Rate – This column shows the maximum safe application rate for each soil which corresponds to the soil maximum intake rate for each soil series. Rates shown assume flat land, good soil structure and soil management. If such conditions do not exist, the maximum rate should be reduced accordingly.

Column (3) - Total Available Water Capacity – These four columns contain, in inches, the total available water capacity (AWC) for the soil series for four effective root depths; 6, 12, 18, and 24 inches. These correspond to common effective root depths. It is recognized that deep-rooted crops and fruit trees have roots at depths greater than 24 inches, the deepest increment shown, but this depth is assumed to be the practical limit for most irrigation applications.

Table 2.1 Maximum Intake Rates and Available Water Capacities for Pennsylvania Soils

(1)	(2)	(3)	(3)	(3)	(3)
Soil Series	**Soil Maximum Intake Rate Inches/Hour**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**
		Effective Root Depth 6”	**Effective Root Depth 12”**	**Effective Root Depth 18”**	**Effective Root Depth 24”**
Abbottstown	0.5	1.1	2.3	3.3	4.0
Albrights	0.6	1.0	1.8	2.6	3.2
Alden	0.6	1.1	2.2	3.2	4.2
Aldino	0.6	1.1	2.0	2.9	3.6
Allegheny	0.8	1.0	2.0	3.0	3.9
Allenwood	0.6	1.0	1.9	2.7	3.6
Allis	0.5	1.1	1.8	2.4	2.8
Alton	1.0	0.6	1.1	1.6	2.1
Alvira	0.5	1.0	1.9	2.9	3.7
Amwell	0.5	1.2	2.3	3.1	3.8
Andover	0.6	0.8	1.4	2.0	2.5
Arendtsville	1.0	0.8	1.6	2.2	2.8
Armagh	0.6	1.2	2.4	3.1	3.8
Arnot	0.5	0.9	1.7	2.1	2.1
Ashton	0.7	1.2	2.4	3.7	4.9
Atherton	0.6	1.1	2.3	3.2	4.1
Athol	0.7	1.0	2.0	2.8	3.7
Atkins	0.6	1.4	2.7	3.9	5.1
Bagtown	1.0	1.0	2.0	3.1	4.1
Baile	0.5	1.3	2.6	3.6	4.7
Barbour	0.7	1.1	2.0	2.9	3.4
Basher	0.6	1.1	2.1	3.0	3.9
Bath	0.6	1.1	2.1	3.0	3.8
Bedington	0.7	0.8	1.7	2.4	3.2
Belmont	1.0	1.1	2.0	3.0	4.0
Beltsville	0.6	1.2	2.4	3.6	4.8
Benson	0.5	1.0	1.8	2.4	2.5
Berks	1.0	0.6	1.1	1.5	1.9
Bermudian	1.0	0.8	1.7	2.5	3.4
Bethesda	0.1	0.8	1.1	1.5	3.4
Birdsboro	0.7	1.1	2.1	3.1	4.0
Blairton	0.6	0.8	1.6	2.3	2.9
Bogart	1.0	0.8	1.7	2.4	3.2
Bowmansville	0.6	1.1	2.2	3.2	4.3
Braceville	0.5	0.7	1.4	2.0	2.5
Brandywine	1.0	0.9	1.7	2.5	3.0
Brecknock	0.7	0.8	1.5	2.2	2.8
Brinkerton	0.5	1.3	2.3	3.3	4.0
Brooke	0.5	1.3	2.4	3.3	4.2

Table 2.1 (Cont'd)

(1)	(2)	(3)	(3)	(3)	(3)
Soil Series	**Soil Maximum Intake Rate Inches/Hour**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**
		Effective Root Depth	**Effective Root Depth**	**Effective Root Depth**	**Effective Root Depth**
		6"	**12"**	**18"**	**24"**
Brownsburg	0.7	1.1	2.2	3.2	4.3
Buchanan	0.6	0.9	1.7	2.5	3.2
Buckingham	0.6	1.1	2.2	3.3	4.4
Bucks	0.6	1.3	2.5	3.7	4.9
Butlertown	0.6	1.2	2.4	3.5	4.6
Cadosia	0.6	1.0	1.7	2.4	2.9
Califon	0.5	1.2	2.4	3.5	4.5
Calvert	0.2	1.3	2.4	3.5	4.6
Calvin	0.8	0.8	1.5	2.2	3.0
Cambridge	0.5	1.3	2.6	3.8	4.9
Canadice	0.5	1.1	2.2	3.1	4.0
Canandaigua	0.6	1.7	3.3	4.4	5.6
Caneadea	0.5	1.4	2.3	3.0	3.7
Canfield	0.4	1.3	2.5	3.6	4.5
Captina	0.6	1.3	2.4	3.3	4.1
Carbo	0.5	1.1	2.0	2.7	3.5
Carrollton	0.6	1.0	1.9	2.8	3.7
Castile	0.7	0.8	1.5	2.0	2.6
Catoctin	1.0	0.8	1.6	2.3	2.9
Cavode	0.6	1.1	2.1	3.2	4.2
Cedarcreek	1.0	0.7	1.4	2.2	2.9
Ceres	0.6	1.0	1.8	2.7	3.5
Chagrin	0.6	1.3	2.6	3.6	4.7
Chalfont	0.5	1.2	2.3	3.1	3.8
Chavies	1.0	0.9	1.8	2.8	3.7
Chenango	1.0	0.7	1.4	2.1	2.7
Chester	0.7	1.1	2.1	3.0	4.0
Chewacla	0.7	1.0	2.0	3.0	3.9
Chicone	0.7	1.1	2.0	2.8	3.6
Chili	0.7	1.0	1.9	2.8	3.5
Chippewa	0.5	1.5	2.6	3.2	3.3
Chrome	0.6	1.1	2.0	2.9	3.7
Clarksburg	0.6	1.0	2.0	2.9	3.8
Clearbrook	0.6	0.6	1.2	1.8	2.4
Clymer	0.7	0.8	1.5	2.2	2.8
Codorus	0.6	1.0	2.0	3.0	4.0
Cokesbury	0.5	1.0	2.0	3.0	3.9
Collamer	0.6	1.1	2.1	3.1	4.2
Colonie	1.0	0.6	1.2	1.6	2.0
Comly	0.6	1.1	2.1	2.9	3.8

Table 2.1 (Cont'd)

(1) Soil Series	(2) Soil Maximum Intake Rate Inches/Hour	(3) Available Water Capacity (Inches) Effective Root Depth 6”	(3) Available Water Capacity (Inches) Effective Root Depth 12”	(3) Available Water Capacity (Inches) Effective Root Depth 18”	(3) Available Water Capacity (Inches) Effective Root Depth 24”
Comus	0.7	1.0	2.0	3.1	4.1
Conestoga	0.7	1.1	2.1	2.9	3.8
Conneaut	0.6	1.1	2.1	3.2	4.2
Conotton	1.0	0.7	1.4	1.9	2.4
Conowingo	0.6	1.2	2.3	3.3	4.4
Cookport	0.6	1.0	1.9	2.6	3.6
Cotaco	1.0	1.0	1.9	2.6	3.2
Covegap	1.0	0.8	1.6	2.3	3.1
Craigsville	1.0	0.7	1.3	2.0	2.6
Croton	0.5	1.2	2.4	3.4	3.8
Culleoka	1.0	0.8	1.7	2.7	3.2
Dekalb	1.0	0.6	1.2	1.7	2.3
Delaware	1.0	1.1	2.1	2.9	3.8
Deposit	1.0	0.7	1.2	1.8	2.3
Dormont	0.5	1.1	2.2	3.2	4.3
Downsville	1.0	1.0	1.9	2.9	3.8
Doylestown	0.6	1.0	1.7	2.5	3.3
Drifton	0.5	1.0	1.9	2.7	3.2
Dryrun	1.0	0.9	1.8	2.7	3.6
Duffield	0.7	1.1	2.2	3.3	4.3
Duncannon	0.7	1.1	2.1	3.0	3.9
Dunning	0.6	1.3	2.5	3.4	4.4
Edgemont	0.3	0.7	1.4	2.0	2.6
Edom	0.6	1.0	1.8	2.5	3.2
Eldred	0.6	1.0	1.8	2.5	3.1
Elk	0.6	1.3	2.5	3.7	4.9
Elkins	0.6	1.3	2.2	3.0	3.9
Elko	0.6	1.1	1.9	2.8	3.6
Elliber	0.8	0.6	1.2	1.8	2.4
Elnora	0.9	0.7	1.4	1.8	2.1
Empeyville	0.5	0.8	1.5	2.2	2.8
Ernest	0.6	1.3	2.6	3.8	4.9
Evendale	0.6	1.0	1.9	2.9	3.8
Fairplay	0.6	1.2	2.4	3.6	4.6
Fairpoint	0.4	0.9	1.5	1.9	2.3
Fitchville	0.6	1.4	2.8	4.0	5.2
Fleetwood	0.6	0.8	1.4	2.1	2.8
Fountainville	0.6	1.2	2.3	3.3	4.3
Frankstown	0.7	1.1	2.1	3.1	3.9
Fredon	0.7	1.1	2.1	3.1	4.0

Table 2.1 (Cont'd)

(1)	(2)	(3)	(3)	(3)	(3)
Soil Series	**Soil Maximum Intake Rate Inches/Hour**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**
		Effective Root Depth	**Effective Root Depth**	**Effective Root Depth**	**Effective Root Depth**
		6"	**12"**	**18"**	**24"**
Fremont	0.6	1.1	2.2	3.2	4.2
Frenchtown	0.5	1.1	2.2	3.2	3.9
Funkstown	0.6	1.1	2.3	3.4	4.4
Gageville	0.6	1.3	2.5	3.5	4.6
Gaila	0.6	0.9	1.7	2.4	3.1
Getzville	0.5	1.1	2.2	3.3	4.4
Gibraltar	0.7	1.2	2.3	3.5	4.6
Gilpin	0.6	1.2	2.1	3.0	3.9
Ginat	0.5	1.3	2.6	3.6	4.5
Gladstone	1.0	0.8	1.7	2.5	3.4
Glenelg	0.6	1.1	2.2	3.3	4.3
Glenford	0.6	1.3	2.5	3.7	4.8
Glenville	0.6	1.1	2.0	2.9	3.5
Gresham	0.5	1.3	2.5	3.7	4.5
Guernsey	0.6	1.3	2.6	3.7	4.6
Hagerstown	0.7	1.3	2.4	3.2	4.0
Halsey	0.6	1.1	2.1	3.0	3.9
Hamlin	0.6	1.2	2.4	3.5	4.6
Hanover	0.6	1.2	2.3	3.2	4.2
Harbor	0.8	0.8	1.6	2.1	2.7
Harborcreek	1.0	0.7	1.3	1.9	2.1
Hartleton	0.8	0.7	1.3	1.8	2.2
Hatboro	0.6	1.1	2.3	3.3	4.4
Haven	0.6	1.2	2.0	2.6	3.2
Hazleton	0.8	0.8	1.4	2.0	2.6
Highfield	0.6	0.8	1.6	2.3	3.1
Hollinger	0.6	1.1	2.0	2.7	3.5
Holly	0.6	1.3	2.6	3.5	4.4
Hornell	0.5	1.1	2.1	2.8	3.5
Howell	0.6	1.1	2.2	3.1	4.1
Hublersburg	0.6	1.0	1.9	2.7	3.6
Huntington	0.6	1.6	2.5	3.8	5.0
Hustontown	0.6	1.1	2.1	3.0	3.8
Itmann	0.8	0.6	1.2	1.7	2.2
Ivory	0.6	1.2	1.9	2.6	3.4
Jimtown	0.6	1.2	2.2	3.1	3.8
Joanna	0.6	1.0	1.8	2.7	3.5
Jugtown	0.6	1.4	2.9	4.1	5.5
Kanona	0.6	1.2	2.1	2.2	2.3
Kedron	0.6	1.0	1.8	2.5	3.2

Table 2.1 (Cont'd)

(1)	(2)	(3)	(3)	(3)	(3)
Soil Series	**Soil Maximum Intake Rate Inches/Hour**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**
		Effective Root Depth	**Effective Root Depth**	**Effective Root Depth**	**Effective Root Depth**
		6"	**12"**	**18"**	**24"**
Keene	0.6	1.4	2.8	4.0	5.2
Kensington	0.6	1.3	2.6	3.6	4.6
Kinzua	0.6	0.9	1.6	2.2	2.9
Klinesville	0.5	0.6	1.0	1.1	1.1
Knauers	0.6	1.2	2.4	3.4	4.1
Kreamer	0.5	1.0	1.8	2.5	3.2
Lackawanna	0.6	1.1	2.1	3.1	3.9
Laidig	0.6	0.7	1.4	2.0	2.6
Lakin	1.0	0.5	0.9	1.2	1.6
Lamington	0.5	1.0	1.9	2.8	3.5
Lamson	0.6	1.1	2.1	3.0	3.9
Lansdale	0.6	1.2	2.1	2.9	3.7
Lantz	0.6	1.1	2.3	3.2	4.1
Lawrenceville	0.6	1.2	2.4	3.3	4.3
Leck Kill	1.0	1.0	1.9	2.7	3.6
Leetonia	1.0	0.2	0.5	0.7	1.0
Legore	0.6	1.1	2.2	3.2	4.3
Lehew	1.0	0.6	1.1	1.6	2.0
Lehigh	0.6	1.0	2.0	3.0	3.9
Letort	0.6	1.1	2.0	2.9	3.7
Lewbath	0.6	1.1	2.1	3.1	4.1
Lewbeach	0.6	1.1	2.1	3.1	3.9
Lewisberry	1.0	0.6	1.2	1.8	2.4
Library	0.6	1.0	1.9	2.6	3.3
Lickdale	0.6	1.2	2.0	2.8	3.5
Linden	0.8	1.0	1.9	2.9	3.8
Lindside	0.6	1.4	2.7	3.9	5.1
Litz	0.6	1.2	1.8	2.2	2.6
Lobdell	0.6	1.3	2.5	3.7	4.9
Lordstown	0.6	1.1	2.2	3.2	4.1
Loudonville	0.6	1.1	2.0	3.0	3.9
Lowell	0.5	1.3	2.4	3.4	4.3
Luray	0.5	1.4	2.7	3.9	5.0
Macove	0.7	0.5	1.2	1.9	2.5
Mahoning	0.6	1.2	4.2	6.1	7.9
Mandy	0.6	0.5	0.9	1.3	1.7
Manlius	0.6	0.8	1.5	2.1	2.7
Manor	0.6	1.0	2.0	3.0	3.9
Maplecrest	0.6	1.8	1.8	2.7	3.6

Table 2.1 (Cont'd)

(1)	(2)	(3)	(3)	(3)	(3)
Soil Series	**Soil Maximum Intake Rate Inches/Hour**	**Available Water Capacity (Inches) Effective Root Depth 6"**	**Available Water Capacity (Inches) Effective Root Depth 12"**	**Available Water Capacity (Inches) Effective Root Depth 18"**	**Available Water Capacity (Inches) Effective Root Depth 24"**
Mardin	0.5	1.1	2.2	3.2	3.6
Markes	0.6	1.0	1.9	2.5	3.1
Matapeake	0.6	1.4	2.8	4.1	5.3
Matewan	1.0	0.6	1.2	1.7	2.2
Mattapex	0.6	1.3	2.5	3.6	4.8
Maurertown	0.5	1.3	2.2	3.1	4.0
Mechanicsburg	0.6	1.3	2.5	3.5	4.5
Meckesville	0.6	0.8	1.7	2.5	3.4
Melvin	0.6	1.3	2.5	3.8	5.0
Mertz	0.6	1.0	1.9	2.9	3.7
Middlebury	0.6	1.1	2.0	2.9	3.8
Mill	0.6	1.4	2.7	3.9	5.0
Millheim	0.6	1.1	2.0	2.8	3.6
Minoa	0.8	1.1	2.1	3.1	4.2
Mongaup	0.6	1.0	2.0	2.9	3.6
Monongahela	0.6	1.3	2.4	3.3	4.3
Montalto	0.8	0.8	1.7	2.6	3.5
Montevallo	0.5	0.6	1.0	1.3	1.4
Morris	0.6	1.3	2.3	2.9	3.0
Morrison	0.8	0.8	1.6	2.2	2.8
Morristown	0.2	0.7	1.2	1.6	2.1
Mount Lucas	0.6	1.2	2.2	3.0	3.8
Mt. Airy	0.6	0.6	1.1	1.5	1.9
Mt. Zion	0.6	1.1	2.3	3.4	4.6
Murrill	0.6	0.8	1.7	2.4	3.1
Myersville	0.7	0.8	1.7	2.7	3.7
Nanticoke	0.3	1.2	2.3	3.2	4.1
Natalie	0.6	0.9	1.7	2.5	2.9
Neshaminy	0.6	1.0	1.8	2.5	3.2
Newark	0.6	1.1	2.1	3.1	4.0
Niagara	0.6	1.2	2.4	3.5	4.6
Nockamixon	0.6	1.1	2.2	3.2	3.8
Nolin	0.6	1.3	2.5	3.8	5.0
Nollville	0.6	1.0	2.0	3.1	4.1
Nolo	0.5	1.1	2.1	3.0	3.8
Norchip	0.5	1.5	2.6	3.2	3.3
Norwich	0.5	1.6	2.6	3.3	3.5
Oakville	1.0	0.5	1.0	1.4	1.9
Oatlands	0.6	1.1	1.6	2.1	2.7

Table 2.1 (Cont'd)

(1)	(2)	(3)	(3)	(3)	(3)
Soil Series	**Soil Maximum intake Rate Inches/Hour**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**
		Effective Root Depth	**Effective Root Depth**	**Effective Root Depth**	**Effective Root Depth**
		6"	**12"**	**18"**	**24"**
Onoville	0.6	1.2	2.2	3.2	3.8
Onteora	0.5	1.1	2.1	2.7	2.8
Ontusia	0.5	1.1	2.0	2.8	2.9
Opequon	0.5	1.1	2.1	2.9	2.9
Oquaga	0.6	0.8	1.3	1.8	2.1
Orrville	0.6	1.2	2.3	3.4	4.4
Otego	0.6	1.2	2.3	3.4	4.5
Othello	0.6	1.0	2.2	3.5	4.8
Ottawa	0.6	1.0	1.6	2.0	2.4
Painesville	0.6	0.7	1.5	2.3	3.2
Papakating	0.6	1.3	2.5	3.7	4.6
Parker	0.8	0.5	1.0	1.4	1.9
Pecktonville	0.6	0.8	1.7	2.6	3.5
Pekin	0.4	1.4	2.7	3.9	4.8
Penargyl	0.6	0.7	1.4	2.3	3.1
Penlaw	0.4	1.1	2.2	3.2	4.1
Penn	0.6	1.0	2.0	3.0	3.9
Pennval	0.6	0.9	1.8	2.6	3.5
Pequea	0.8	0.9	1.7	2.5	3.2
Phelps	0.6	1.0	1.9	2.6	3.3
Philo	0.6	1.4	2.8	4.0	5.1
Pierpont	0.4	1.3	2.5	3.7	4.4
Platea	0.5	1.3	2.6	3.7	4.6
Pocono	0.6	0.7	1.3	1.8	2.4
Pompton	0.6	1.0	1.9	2.7	3.6
Pope	1.0	0.8	1.6	2.5	3.3
Portville	0.5	1.2	2.4	3.5	4.3
Potomac	1.0	0.5	0.8	1.1	1.4
Purdy	0.4	1.3	2.4	3.2	4.1
Rainsboro	0.6	1.4	2.6	3.8	5.0
Raritan	0.6	1.1	2.0	2.9	3.7
Ravenna	0.4	1.3	2.5	3.7	4.5
Ravenrock	0.8	0.9	1.8	2.7	3.6
Rayne	0.6	1.0	1.9	2.7	3.5
Readington	0.6	1.3	2.1	2.8	3.4
Reaville	0.6	1.0	1.8	2.4	2.9
Red Hook	0.6	1.0	1.7	2.3	3.0
Rexford	0.4	1.0	1.9	2.6	3.2
Rimer	0.6	0.5	1.2	1.8	2.7
Riverhead	0.6	1.0	1.9	2.6	3.2

Table 2.1 (Cont'd)

(1)	(2)	(3)	(3)	(3)	(3)
Soil Series	**Soil Maximum intake Rate Inches/Hour**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**
		Effective Root Depth 6"	**Effective Root Depth 12"**	**Effective Root Depth 18"**	**Effective Root Depth 24"**
Rohrersville	0.6	1.1	2.3	3.4	4.6
Rowland	0.6	1.0	1.9	2.9	3.8
Rushtown	1.0	0.7	1.3	1.8	2.3
Ryder	0.7	1.2	2.2	3.2	4.2
Sassafras	0.7	0.8	1.6	2.5	3.5
Scio	0.6	1.2	2.4	3.5	4.7
Sciotoville	0.6	1.3	2.5	3.7	4.8
Sebring	0.6	1.4	2.7	3.9	5.0
Sewell	1.0	0.5	1.1	1.6	2.2
Sheffield	0.4	1.1	2.0	2.9	3.6
Shelmadine	0.5	1.0	1.7	2.4	3.2
Shelocta	0.6	0.6	1.5	2.4	3.3
Shohola	0.6	0.8	1.6	2.3	3.1
Shongo	0.5	1.2	2.3	3.4	4.4
Sideling	0.6	0.7	1.4	2.2	2.9
Skidmore	0.7	0.6	1.2	1.7	2.1
Skytop	1.0	0.5	1.1	1.7	2.3
Sloan	0.6	1.3	2.6	4.0	5.0
Stanhope	0.6	1.2	2.4	3.7	4.9
Steff	0.6	1.1	2.4	3.7	4.9
Steinsburg	0.7	0.7	1.5	2.2	2.7
Suncook	1.0	0.6	1.1	1.5	1.8
Swanpond	0.5	1.0	2.0	3.0	3.9
Swartswood	0.6	0.6	1.2	1.8	2.4
Sweden	0.6	0.9	1.9	2.7	3.5
Teegarden	0.6	1.3	2.6	3.5	4.4
Thorndale	0.6	1.1	2.1	3.0	3.8
Thurmont	0.7	1.0	1.9	2.9	3.8
Tilsit	0.6	1.1	2.3	3.4	4.5
Timberville	0.7	1.0	1.9	2.8	3.7
Tioga	0.7	1.1	2.0	2.9	3.7
Titusville	0.6	1.3	2.4	3.3	4.3
Towerville	0.6	1.0	1.9	2.8	3.7
Towhee	0.6	1.1	2.0	2.9	3.8
Trego	0.6	0.9	1.8	2.6	3.4
Tughill	0.6	0.9	1.8	2.2	2.6
Trumbull	0.6	1.4	2.3	3.0	3.7
Tunkhannock	0.8	0.7	1.4	2.0	2.6
Tyler	0.6	1.2	2.3	3.4	4.1
Tyner	0.8	0.7	1.3	1.8	2.3

Table 2.1 (Cont'd)

(1)	(2)	(3)	(3)	(3)	(3)
Soil Series	**Soil Maximum Intake Rate Inches/Hour**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**	**Available Water Capacity (Inches)**
		Effective Root Depth 6"	**Effective Root Depth 12"**	**Effective Root Depth 18"**	**Effective Root Depth 24"**
Unadilla	0.6	1.2	2.4	3.5	4.7
Ungers	0.6	0.8	1.6	2.3	3.0
Upshur	0.5	1.3	2.0	2.7	3.3
Urbana	0.4	1.2	2.4	3.4	4.3
Valois	0.6	0.7	1.4	2.1	2.7
Vandergrift	0.6	1.1	2.0	2.7	3.5
Vanderlip	1.0	0.5	1.0	1.5	2.0
Varilla	1.0	0.7	1.4	1.8	2.3
Venango	0.6	1.3	2.6	3.8	4.3
Vly	0.6	0.9	1.6	2.2	2.8
Volusia	0.5	1.2	2.4	3.5	4.6
Wakeville	0.6	1.2	2.4	3.5	4.6
Warners	0.6	1.2	2.4	3.5	4.6
Washington	0.6	1.2	2.3	3.4	4.5
Wasnot	0.5	0.5	1.1	1.7	1.7
Warchung	0.6	1.1	2.1	3.2	4.2
Watson	0.6	0.8	1.7	2.5	3.3
Wayland	0.6	1.1	2.2	3.3	4.4
Wehadkee	0.7	1.1	2.3	3.3	4.4
Weikert	0.5	0.7	1.0	1.1	1.1
Weinbach	0.6	1.2	2.4	3.4	4.5
Wellsboro	0.5	1.1	2.1	3.1	3.8
Westmoreland	0.7	1.0	1.9	2.8	3.7
Weverton	0.7	0.8	1.1	1.5	1.8
Wharton	0.6	1.1	2.0	2.9	3.2
Wheeling	0.7	0.9	1.8	2.5	3.2
Wick	0.6	1.1	2.2	3.2	4.2
Willdon	0.5	1.1	2.1	3.1	3.5
Willowemoc	0.5	1.1	2.1	3.1	3.8
Wiltshire	0.6	1.0	2.0	3.0	3.9
Woodstown	0.6	0.8	1.6	2.8	3.9
Wooster	0.6	1.1	2.2	3.1	4.0
Worsham	0.3	1.3	2.4	3.5	4.6
Worth	0.6	0.8	1.5	2.2	2.9
Wurno	0.6	0.8	1.4	1.8	2.3
Wurtsboro	0.6	0.7	1.4	2.2	2.9
Wyalusing	1.0	1.0	1.9	2.7	3.5
Wyoming	1.0	0.6	1.1	1.6	2.1
Zipp	0.6	1.1	2.2	3.2	4.3
Zoar	0.6	1.0	2.0	2.9	3.7

(e) Properties Affecting Water Intake Rates

The three most important soil properties affecting a soil's water intake rate are (a) the soil's texture, (b) the soil's structure and (c) how well the soil structure is developed.

Table 2.6 of the NEH, Part 652 relates the soil water intake rates to soil texture. The part of this table relating to sprinkler irrigation is repeated here as Table 2.2.

Other references present maximum water intake rates for various applicable conditions. The Midwest Plan Service (1985) has a table that relates maximum intake rates to soil texture, degree of drainage, and cover (see Table 2.3), Tables 2.1 and 2.2 are provided to be the primary sources of determining values for maximum intake rates for soils. Table 2.3 is provided to offer fine tuning advice for possible modification of the values in Table 2.1 and 2.2 if needed.

The second column of Table 2.1 gives recommended maximum irrigation intake rates for each Pennsylvania soil series. The application rate chosen for each irrigation design should not exceed the intake values given in Table 2.1 unless measures are implemented to mitigate runoff and translocation.

Table 2.2 Soil Intake Rates by Soil Texture

Soil Texture	Soil Intake Rate (in/hr)
Clay, Silty Clay	0.1 to 0.2
Sandy Clay, Silty Clay Loam	0.1 to 0.4
Clay Loam, Sandy Clay Loam	0.1 to 0.5
Silt Loam, Loam	0.5 to 0.7
Very Fine Sandy Loam, Fine Sandy Loam	0.3 to 1.0
Sandy Loam, Loamy Very Fine Sand	0.3 to 1.25
Loamy Fine Sand, Loamy Sand	0.4 to 1.5
Fine Sand, Sand	0.5 +
Course Sand	1.0 +

Table 2.3 Maximum Soil Intake Rates. (Midwest Plan Service. 1985)

Soil Characteristics	Covered (in/hr)	Bare (in/hr)
Clay; very poorly drained.	0.30	0.15
Silty surface; poorly drained clay and clay pan subsoil.	0.40	0.25
Medium textured surface soil; moderate to imperfectly drained profile.	0.50	0.30
Silt loam, loam, and very sandy loam; well to moderately well drained.	0.60	0.40
Loamy sand, sandy loam, or peat; well drained.	0.90	0.60

Chapter 3 Crops -- 652.0308 PA State Supplement

The primary crops irrigated in Pennsylvania are vegetables, sweet corn, melons, blueberries, brambles, grapes, and tree fruit. Field corn, soybeans, hay and small grains are rarely irrigated.

(a) Critical Growth Periods
In addition to the water needed to ensure healthy, growing crops, most crops have critical periods during the growing season when non-stressful soil water levels must be maintained to obtain high quality and quantity yields. The critical period for most crops occurs during the part of the growing season of pod, fruit, tuber, or ear formation and development.

If irrigation water supplies are limited, the best use of the irrigation water supply is to irrigate during the critical growth period of the crop.

Table 3.1 Critical Periods When Crops Need Water Most

Crop	Critical Periods When Crops Need Water Most
Alfalfa	Start of flowering and after cutting
Apples	Bud stage, fruit enlargement, and pre-harvest period
Blueberries	Bloom through fruit sizing
Corn, grain	Tasseling, silking, and early stage of ear development
Corn, sweet	Tasseling, silking, and early stage of ear development
Cauliflower	Entire growing season
Eggplant	Flowering and fruit development
Grapes	Blossom to beginning stages of fruit ripening
Lettuce	Head development
Onions	Bulb enlargement
Peaches	Final fruit enlargement and pit hardening
Peppers	Flowering, fruit development, fast enlarging stage
Potatoes	Tuber set and tuber enlargement
Pumpkins	Fruit stage
Raspberries	Bloom through harvest
Soybeans	Flowering and fruiting stage
Strawberries	Fruit development through harvest
Tomatoes	Early flowering, fruit set, and enlargement
Watermelons	Flowering and fruit development

(b) Salinity Tolerance
High levels of salt accumulation in the root zone of the soil may limit plant growth. Because of the larger annual rainfall amounts that normally occur in Pennsylvania, especially during the non-crop growing periods, build-up of salts within the plant root zones is not an issue. If, for whatever reason, salt should begin to build up in a soil, additional irrigation may be needed to leach the salts from the soil profile.

(c) Effective Rooting Depths
The effective root depth is the depth of soil used by the majority of the plant roots to obtain most of the water and plant nutrients stored in the soil. It is not the same as the maximum root depth. As a rule of thumb about 70% of the water extracted by the rooting system is obtained from the top half of the root depth; about 20% from the next lower quarter; and about 10% from the soil in the deepest quarter of the root depth.

Root depth will vary according to the soil depth, fertility management, age of the plant, and the rooting characteristics of the plant. Each crop has its own root development characteristics, which vary only slightly under adequate soil-water conditions in a given soil profile.

Application of irrigation water should be limited to an amount that will penetrate only to the effective root depth. Applications in excess of this amount will result in waste of water and added pumping cost. Also, in lighter textured soils, heavy applications may cause leaching of plant nutrients below the reach of the plant feeder roots.

Effective root depths for selected crops irrigated in Pennsylvania are shown in Table 3.2. The listed depths are generally satisfactory for water management purposes. There may be occasions where field conditions indicate that effective root depth other than those listed may be more appropriate.

Table 3.2 Effective Rooting Depths for Selected Pennsylvania Crops

Crop	Effective Rooting Depth (Inches)
Alfalfa	36
Apples	30
Blueberries	18
Cauliflower	18
Corn, Grain	24
Corn, Sweet	24
Eggplant	12
Grape	36
Lettuce	6
Onions	12
Peaches	30
Peppers	12
Potatoes	18
Pumpkins	18
Raspberries	18
Soybeans	24
Strawberries	12
Tomatoes	18
Watermelons	24

Each crop was given an effective rooting depth based on:

1. Depth of soil to which the larger proportion of the total root system develops when the marketable part of the crop is being produced.

2. Research and experience regarding the overall water needs of each crop.

3. The kind of soil in which crops are commonly grown in Pennsylvania.

Note: Depth of irrigation during the early-growing-season of each crop may be reduced to account for the soil's limited water holding capacity in the more-shallow root system, if appropriate.

Chapter 4 Water Requirements -- 652.0408 PA State Supplement

(a) General

This chapter provides guidance on the total depth of water a crop needs to grow and produce an outstanding yield of fruit, vegetables, grain or other product, the **Total Water Depth Needs of Each Crop (Seasonal ET)**. In addition, an estimate of how much irrigation water a grower will most likely need to apply during the growing season taking into account the natural precipitation expected in the three climate regions of Pennsylvania, the **Net Water Depth Needs of Each Crop (Seasonal Irrigation)**.

(b) Crop Evapotranspiration, ET

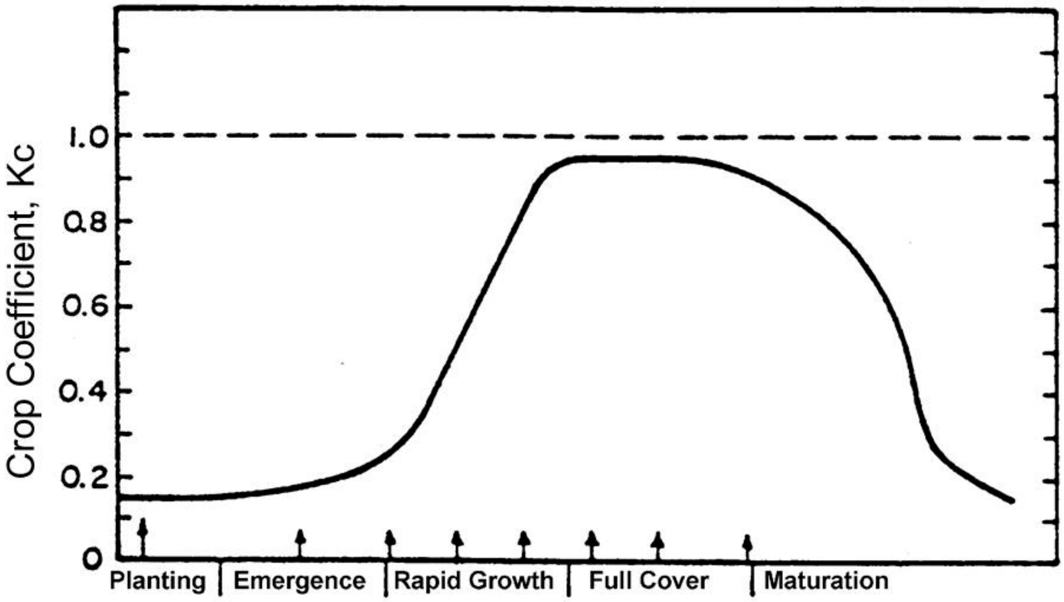
Plants must have a continuous supply of readily available water to maintain rapid, vigorous growth. The water transpired by the crop plus the water evaporated directly from the field or plant surface is called evapotranspiration. The amount of water evapotranspired from any irrigated field on any given day is related to the air temperature, the number of daylight hours, the crop characteristics, and the stage of crop growth. Other factors, such as wind speed, solar radiation, and relative humidity, also affect water usage rates by plants. Because of the difficulty and expense of measuring ET for each grower's crop, weather data is generally used to develop a reference ET value that then can be related to each crop using a crop coefficient (Kc).

A seasonal representation of how the crop coefficient, Kc, changes throughout the growing season is shown in Figure 4.1. All crops have relatively low water use rates when they are young, and their roots are actively growing. Their highest rates usually occur as they approach the stage of maximum vegetative canopy cover and/or fruit or product development. For comparable stages of crop growth, water use rates are greater on long, hot, windy, summer days when the ET rates can reach nearly 0.30 in/day, than on calm, cool, cloudy days, when the ET rates may decline to nearly zero. In Pennsylvania, research data (Toro, 1966) shows that vigorously growing crops require, on average, about 0.20 inches of water per day (Kc = 1.0) introduced into the area covered by the crop canopy. For crops that develop a full canopy cover or for crops that will be irrigated, the 0.20 in/day is a good design ET rate. For crops that do not develop full canopy covers (grapes, tree fruits) the design ET rate should only be applied to the canopy area.

The average daily ET rate can be estimated for any time during the crop growth period in Pennsylvania by multiplying the average daily design ET rate of 0.20 inches/day times the crop coefficient, Kc for the period of plant growth from Figure 4.1. For example during the first week after planting, the daily ET rate will be about 0.17 (Figure 4.1) times 0.20 inches/day or 0.034 inches/day applied to the canopy of the crop. If the same evaluation is applied when the plants are at full cover, Kc=0.95 (Figure 4.1) the daily ET rate will be about 0.19 inches/day.

The average daily or design ET rate of 0.20 inches/day is generally recommended for use for Pennsylvania. Daily ET rates can vary greatly as soils, irrigation types, temperature, humidity, cloud cover, and wind change. The maximum ET rates may be considerably higher than the design ET rate recommended above. Based on the analysis conducted using the NRCS IWRpm software version 1.1 (2006) the highest daily ET rates expected for each crop in each region of Pennsylvania are shown in the next to last column of Tables 4.1 and 4.2. These maximum daily ET rates generally need not be used in irrigation designs, unless a very detailed design is required or unless the IWRpm software is being used.

Figure 4.1 How the Crop Coefficient, Kc, Changes During the Growing Season.



(c) Two Ways to Look at Crop Water Needs

Two different methods of estimating crop-water needs will be presented in this chapter. The first is the Total Water Depth Needs (Seasonal ET) of the various crops. The second is the Net Water Depth Needs (Seasonal Irrigation) of the various crops. The data presented in both of these sections should be useful to the grower and irrigation system designer especially as it pertains to estimating the volume of water the grower should plan to store, or have available, to supply the irrigation needs of the crop.

When designing an irrigation system for a specific crop growing in a specific soil, the resulting irrigation system; the distribution system, the pipes, and the pump, must be sized to economically apply the peak daily ET depth needed under the assumption that natural rain will not contribute any water to the growing crop. The assumption is that the resulting irrigation system must be capable of applying all the water needed by that specific crop if there is no natural precipitation. Sizing the irrigation system to apply less water that the Total Water Depth Needed (Seasonal ET) by the crop would not provide sufficient capacity during an extremely long period of no rain when the irrigation system is the only source of crop-needed water.

Conversely, if natural rain does occur during the growing season, the irrigation system should be used only to apply the water natural rain has not contributed to the growing crop. The available rainfall data shows that rarely can a crop be grown, from planting to harvest in Pennsylvania, when there is not at least one period of several weeks when there is no natural precipitation. In this most likely occurrence, the irrigation system will only be used when needed and as long as is needed. Making these decisions that allow the system operator to decide when and how much irrigation water to apply will be presented in Chapter 9. By utilizing the irrigation system only on an as-needed basis, the grower will most likely **<u>not</u>** need to apply the full depth of the Total Water Depth Needed by the crop but can take advantage of the natural rain to contribute to the crop's water needs. When the water contributed by natural rain is subtracted from the Total Water Depth Needed by the crop, the result is the Net Water Depth Needed (Seasonal Irrigation) by the crop. This Net Water Depth Need is a good estimate of the irrigation water depth or volume the grower will probably need to have available during the crop growing season, so the crop can be properly irrigated. The Net Water Depth Needed is the best guidance that can be provided to a grower about how much water should be stored, possibly in a pond, or available from a stream or well so a specific crop can be successfully irrigated.

(d) Total Water Depth Needs of Each Crop

The total depth of water needed by selected crops during their period of growth, from planting to harvest have been estimated using the NRCS IWRpm software version 1.1 (2006) program and are shown in the right-hand columns of both Table 4.1 and 4.2 as “Seasonal ET”. These also represent the expected needs for growing these crops in a greenhouse or high tunnel where no precipitation is contributed.

The Total Water Depth Needed (Seasonal ET) amounts are crop and climate dependent and thus should be the same for both sprinkler and drip irrigation systems. The only difference would be the efficiencies of the two types of irrigation systems.

Table 4.1 Net Irrigation Water Requirements for selected crops in three regions of Pennsylvania during years of **NORMAL** rainfall. Peak Daily ET rates and Seasonal ET depths are also given. 2/

Crop	PA Climate Region	Apr. (in)	May (in)	June (in)	July (in)	Aug. (in)	Sept. (in)	Oct. (in)	Seasonal Irrigation (in)	Peak Daily ET (in/day)	Seasonal ET (in) 1/
	North	0.4	2.7	2.2	3.5	2.7	1.1		12.6	0.24	27.1
Alfalfa	Central	1.0	3.1	3.2	4.2	3.3	1.2		16.0	0.27	30.7
	Southeast	1.3	3.7	4.2	4.8	3.6	1.6		19.2	0.29	33.7
	North		1.4	2.8	3.9	3.6	2.4	0.6	14.7	0.26	29.6
Apples	Central	0.1	1.9	3.9	4.6	4.4	2.5	0.7	18.1	0.30	33.2
	Southeast	0.2	2.4	5.0	5.2	4.8	2.9	1.1	21.6	0.32	36.6
	North		0.3	1.6	2.8	2.7	1.4		8.8	0.20	22.0
Blueberries	Central		0.6	2.6	3.3	3.3	1.5		11.3	0.23	24.6
	Southeast		1.1	3.5	3.9	3.7	1.8	0.1	14.1	0.25	27.1
	North				1.0	2.9	1.6		5.5	0.20	13.5
Cauliflower	Central				1.7	3.6	1.8		7.1	0.22	14.9
	Southeast			0.1	2.2	3.9	2.0		8.2	0.24	16.4
	North			0.8	3.3	3.4	1.7		9.2	0.23	21.1
Corn, grain	Central			1.7	3.9	4.1	1.9		11.6	0.26	23.4
	Southeast		0.1	2.7	4.5	4.5	2.3		14.1	0.28	25.8
	North			1.0	3.4	3.9	2.0		10.3	0.24	22.0
Corn, sweet	Central			1.9	4.1	4.6	2.1		10.6	0.27	24.5
	Southeast		0.3	2.8	4.7	5.1	2.4		15.3	0.29	26.9
	North			0.4	2.6	2.9	1.2		7.1	0.20	17.7
Eggplant	Central			1.2	3.1	3.6	1.3		9.2	0.22	19.6
	Southeast			2.1	3.6	3.9	1.6		11.2	0.25	21.6
	North		0.3	1.4	2.4	2.3	1.3	0.1	7.8	0.18	20.7
Grapes	Central		0.5	2.3	2.9	2.9	1.4	0.2	10.2	0.21	23.0
	Southeast		0.8	3.2	3.4	3.2	1.6	0.6	12.8	0.22	25.4

1/ Seasonal ET is the total yearly crop water depth needed considering no rainfall contribution

2/ Shaded cells represent the month with the largest net water depth need

Table 4.1 (Normal Cont'd). 2/

Crop	Region	Apr. (in)	May (in)	June (in)	July (in)	Aug. (in)	Sept (in)	Oct. (in)	Seasonal Irrigation (in)	Peak Daily ET (in/day)	Seasonal ET (in) 1/
Lettuce	North			0.4	1.9	2.7	2.0	0.7	7.7	0.19	20.3
	Central		0.6	2.7	3.8	3.4			10.5	0.25	22.0
	Southeast	0.1	1.1	3.6	4.4	3.8			13.0	0.27	24.0
Onions	North		0.1	2.3	0.9				3.3	0.17	9.5
	Central	0.6	2.7	1.5					4.8	0.20	11.2
	Southeast	0.9	3.2	2.2					6.3	0.22	12.3
Peaches	North		1.3	2.4	3.4	3.1	1.9	0.3	12.4	0.24	27.6
	Central	0.2	1.7	3.5	4.1	3.8	2.0	0.5	15.8	0.27	30.9
	Southeast	0.5	2.2	4.5	4.6	4.2	2.3	0.9	19.2	0.29	34.2
Peppers	North			1.6	3.2	2.1			6.9	0.22	16.6
	Central		0.3	2.7	3.8	2.8			9.6	0.26	18.7
	Southeast		0.3	3.6	4.4	3.1			11.4	0.27	20.3
Potatoes	North		0.4	2.6	3.7	3.4	1.2		11.3	0.25	25.1
	Central		0.9	3.7	4.4	4.1	1.3		14.4	0.29	28.3
	Southeast	0.1	1.5	4.8	5.0	4.6	1.6		17.6	0.31	31.1
Pumpkins	North				0.8	2.4	1.8	0.1	5.1	0.18	13.9
	Central				1.4	3.1	1.9	0.1	6.5	0.19	15.2
	Southeast			0.1	1.9	3.4	2.1	0.4	7.9	0.22	16.9
Raspberries	North		0.5	1.4	2.4	2.3	1.2		7.8	0.18	20.8
	Central		0.9	2.3	2.9	2.9	1.3		10.3	0.21	23.3
	Southeast		1.4	3.2	3.4	3.2	1.6	0.1	12.9	0.22	25.7
Soybeans	North				2.2	3.3	2.3	0.5	8.3	0.22	19.9
	Central			0.7	2.7	4.1	2.5	0.6	10.6	0.24	21.9
	Southeast			1.5	3.2	4.4	2.8	1.1	13.0	0.27	24.4

1/ Seasonal ET is the total yearly crop water depth needed considering no rainfall contribution
2/ Shaded cells represent the month with the largest net water depth need

Table 4.1 (Normal Cont'd). 2/

Crop	Region	Apr. (in)	May (in)	June (in)	July (in)	Aug. (in)	Sept. (in)	Oct. (in)	Seasonal Irrigation (in)	Peak Daily ET (in/day)	Seasonal ET (in) 1/
Strawberries	North		0.2	1.5	1.9	1.8	0.8		6.2	0.16	19.1
	Central		0.5	2.4	2.4	2.3	0.9		8.5	0.18	21.4
	Southeast		1.0	3.3	2.8	2.5	1.3		10.9	0.20	23.6
Tomatoes	North			1.1	3.4	3.4	1.4		9.3	0.24	21.0
	Central			2.1	4.1	4.1	1.5		11.8	0.27	23.4
	Southeast		0.3	3.0	4.6	4.5	1.7		14.1	0.29	25.6
Watermelons	North			0.5	3.3	3.6	1.4		8.8	0.23	19.6
	Central			1.4	3.9	4.4	1.5		11.2	0.26	21.8
	Southeast			2.3	4.5	4.8	1.7		13.3	0.29	23.9

1/ Seasonal ET is the total yearly crop water depth needed considering no rainfall contribution
2/ Shaded cells represent the month with the largest net water depth need

Table 4.2 Net Irrigation Water Requirements for selected crops in three regions of Pennsylvania during years of **DRY** rainfall. Peak Daily ET rates and Seasonal ET depths are also given. 2/

Crop	Region	Apr. (in)	May (in)	June (in)	July (in)	Aug. (in)	Sept. (in)	Oct. (in)	Seasonal Irrigation (in)	Peak Daily ET (in/day)	Seasonal ET (in) 1/
Alfalfa	North	0.6	3.0	2.6	3.9	3.0	1.5		14.6	0.24	27.1
	Central	1.2	3.5	3.5	4.6	3.6	1.6		18.0	0.27	30.7
	Southeast	1.6	4.0	4.4	5.1	4.0	2.0		21.1	0.29	33.7
Apples	North		1.8	3.2	4.3	4.0	2.7	0.8	16.8	0.26	29.6
	Central	0.2	2.3	4.2	5.0	4.7	2.8	0.9	20.1	0.30	33.2
	Southeast	0.4	2.7	5.2	5.6	5.1	3.2	1.4	23.6	0.32	36.6
Blueberries	North		0.7	2.0	3.1	3.0	1.8		10.6	0.20	22.0
	Central		1.1	2.8	3.7	3.6	1.9		13.1	0.23	24.6
	Southeast		1.5	3.7	4.2	4.0	2.2	0.2	15.8	0.25	27.1
Cauliflower	North				1.5	3.2	1.9		6.6	0.20	13.5
	Central				2.1	3.8	2.1		8.0	0.22	14.9
	Southeast			0.2	2.5	4.2	2.4		9.3	0.24	16.4
Corn, grain	North			1.3	3.6	3.7	2.1		10.7	0.23	21.1
	Central		0.1	2.2	4.3	4.4	2.3		13.3	0.26	23.4
	Southeast		0.3	2.9	4.8	4.8	2.7	0.1	15.6	0.28	25.8
Corn, sweet	North		0.1	1.4	3.8	4.2	2.2		11.7	0.24	22.0
	Central		0.3	2.2	4.5	4.9	2.4		14.3	0.27	24.5
	Southeast		0.6	3.0	5.0	5.4	2.8		16.8	0.29	26.9
Eggplant	North			0.8	2.9	3.2	1.5		8.4	0.20	17.7
	Central			1.7	3.5	3.9	1.6		10.7	0.22	19.6
	Southeast		0.1	2.4	4.0	4.3	1.9		12.7	0.25	21.6
Grapes	North		0.5	1.8	2.7	2.6	1.6	0.3	9.5	0.18	20.7
	Central		0.8	2.6	3.2	3.2	1.7	0.4	11.9	0.21	23.0
	Southeast		1.1	3.4	3.7	3.5	2.0	0.8	14.5	0.22	25.4

1/ Seasonal ET is the total yearly crop water depth needed considering no rainfall contribution
2/ Shaded cells represent the month with the largest net water depth need

Table 4.2 (Dry Cont'd). 2/

Crop	Region	Apr. (in)	May (in)	June (in)	July (in)	Aug. (in)	Sept. (in)	Oct. (in)	Seasonal Irrigation (in)	Peak Daily ET (in/day)	Seasonal ET (in) 1/
Lettuce	North		0.1	0.9	2.2	3.0	2.2	0.9	9.3	0.19	20.3
	Central	0.1	1.1	3.0	4.2	3.7			12.1	0.25	22.0
	Southeast	0.3	1.4	3.9	4.7	4.1			14.4	0.27	24.0
Onions	North		0.3	2.6	1.1				4.0	0.17	9.5
	Central	0.8	3.0	1.7					5.5	0.20	11.2
	Southeast	1.2	3.5	2.3					7.0	0.22	12.3
Peaches	North	0.3	1.8	2.8	3.8	3.5	2.2	0.6	15.0	0.24	27.6
	Central	0.4	2.1	3.8	4.4	4.1	2.3	0.7	17.8	0.27	30.9
	Southeast	0.7	2.5	4.7	5.0	4.5	2.7	1.1	21.2	0.29	34.2
Peppers	North		0.2	2.1	3.6	2.4			8.3	0.22	16.6
	Central		0.3	3.0	4.2	3.0			10.5	0.26	18.7
	Southeast		0.6	3.8	4.7	3.4			12.5	0.27	20.3
Potatoes	North		0.9	3.0	4.1	3.7	1.5		13.2	0.25	25.1
	Central	0.1	1.4	4.0	4.8	4.4	1.6		16.3	0.29	28.3
	Southeast	0.3	1.8	5.0	5.4	4.8	1.9		19.2	0.31	31.1
Pumpkins	North				1.2	2.7	2.0	0.2	6.1	0.18	13.9
	Central				1.8	3.3	2.2	0.3	7.6	0.19	15.2
	Southeast			0.2	2.2	3.7	2.5	0.5	9.1	0.22	16.9
Raspberries	North		0.9	1.8	2.7	2.6	1.5		9.5	0.18	20.8
	Central		1.3	2.6	3.2	3.2	1.7		12.0	0.21	23.3
	Southeast	0.1	1.7	3.4	3.7	3.5	2.0	0.1	14.5	0.22	25.7
Soybeans	North			0.3	2.5	3.7	2.6	0.8	9.9	0.22	19.9
	Central			1.0	3.1	4.4	2.8	0.9	12.2	0.24	21.9
	Southeast			1.7	3.5	4.8	3.1	1.3	14.4	0.27	24.4

1/ Seasonal ET is the total yearly crop water depth needed considering no rainfall contribution
2/ Shaded cells represent the month with the largest net water depth need

Table 4.2 (Dry Cont'd). 2/

Crop	Region	Apr. (in)	May (in)	June (in)	July (in)	Aug. (in)	Sept. (in)	Oct. (in)	Seasonal Irrigation (in)	Peak Daily ET (in/day)	Seasonal ET (in) 1/
Strawberries	North		0.6	1.9	2.2	2.0	1.2		7.9	0.16	19.1
	Central		1.0	2.7	2.7	2.6	1.3		10.3	0.18	21.4
	Southeast		1.4	3.6	3.2	2.8	1.6	0.1	12.7	0.20	23.6
Tomatoes	North		0.1	1.6	3.8	3.7	1.6		10.8	0.24	21.0
	Central		0.3	2.4	4.4	4.4	1.8		13.3	0.27	23.4
	Southeast		0.6	3.2	5.0	4.8	2.1		15.7	0.29	25.6
Watermelons	North			1.0	3.6	4.0	1.6		10.2	0.23	19.6
	Central			1.8	4.3	4.7	1.8		12.6	0.26	21.8
	Southeast		0.1	2.6	4.8	5.1	2.1		14.7	0.29	23.9

1/ Seasonal ET is the total yearly crop water depth needed considering no rainfall contribution

2/ Shaded cells represent the month with the largest net water depth need

(e) Peak Evapotranspiration

Based on the NRCS IWRpm analysis peak evapotranspiration rates were estimated for each crop in each of the three regions of Pennsylvania (see Figure 4.2). These peak evapotranspiration rates are given in the next to the last column of Tables 4.1 and 4.2. These peak rates are the same in both tables and are based on weather extremes recorded over the period of weather records at each of the 72 Pennsylvania weather stations.

The 2 right hand columns are exactly the same for both tables 4.1 and 4.2 as Peak ET and Seasonal ET are independent of the Normal or Dry Year designations and are independent of the net water (seasonal irrigation) needs of each crop.

an increase in clay content, flow rate, and irrigation run time. The shape of the wetted volume depends on soil tension forces and gravity. In clayey soils, the tension forces are very strong and gravity forces are relatively unimportant. Flow from an emitter moves horizontally and vertically at almost the same rate to form a circular bulb-shaped wetted volume. Unlike clayey soils, gravity plays a more important role in sandy soils. The result is a cylinder-shaped wetted volume that is deeper than the diameter. Coarse textured soils, therefore, require more emitters or closer emitter spacing to obtain adequate irrigation for root development. Emitters must be placed so that soil wetting from the emitters applies water to and wets at least 25-33% of the root volume.

After irrigation is stopped, soil water will redistribute until equilibrium is reached. The diameter of the soil wetted by an emitter is listed in Table 6.8 for various soil textures. Generally, emitters with high flow rates (2 gph) that operate a long time wet larger areas.

(e.3.e) Distribution Lines – The microirrigation distribution system is a network of pipes, tubing, and valves. Generally main lines 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 pipe. Fittings are cemented or are connected using O-ring gaskets for water tightness. Manifolds can also be flexible PE tubing either buried or laid on the ground surface. Mainlines and manifolds are typically buried to provide access and limit potential equipment damage. Lateral lines are normally 16mm – 20mm (½” – ¾”), diameter polyethylene (PE) flexible tubing laid on the soil surface. Lateral fittings generally are slip joint with hose clamps for water tightness.

Table 6.8 Diameter of Soil Wetted by a Single Emitter

Soil Texture	Wetted Diameter, ft
Coarse Sand	2
Sand	2
Fine Sand	2
Loamy Sand	3
Loamy Coarse Sand	3
Loamy Fine Sand	3
Loamy Very Fine Sand	4
Sandy Loam	4
Fine Sandy Loam	4.5
Very Fine Loam	4.5
Loam	5
Silt Loam	5
Sandy Clay Loam	5
Clay Loam	6
Silty Clay Loam	6
Sandy Clay	7
Silty Clay	7
Clay	7

(e.3.f) Control Devices and Management Tools

(e.3.f.1) “On” and “Off” Valves –There are many types of valves on the market. In general, there are two types of valves; gate valves and globe valves. Gate valves are used to turn the flow of water “on” or “off”. Globe valves will turn the flow of water “on” or “off”, but they can also be automated to open and close in response to external stimuli such as air or water pressure or electric voltage. Globe valves can also be used to

(f) Dates When Crops Begin and End Growth

The dates when various crops are typically planted, transplanted, or begin to grow following the winter dormant period were obtained from Penn State Extension Specialists, neighboring states, national NRCS guidance and common knowledge. The End of the Growth period dates were obtained from the same sources. These dates for selected crops grown in Pennsylvania are given in Column 2 of Table 4.3.

Table 4.3 Crop Growing Seasons.

CROP	GROWING SEASON	
	Begin Growth	End Growth
Alfalfa	30-Mar	15-Oct
Apples	10-Apr	30-Oct
Blueberries	15-Apr	15-Oct
Cauliflower	20-Jun	30-Sep
Corn, grain	10-May	15-Oct
Corn, sweet	1-May	30-Sep
Eggplant	15-May	30-Sep
Grapes	1-May	30-Oct
Lettuce	1-May	5-Sep
Onion	1-Apr	20-Jun
Peaches	1-Apr	30-Oct
Peppers	1-May	30-Aug
Potatoes	30-Mar	1-Oct
Pumpkins	20-Jun	20-Oct
Raspberries	15-Apr	15-Oct
Soybeans	30-May	10-Nov
Strawberries	15-Apr	15-Oct
Tomatoes	1-May	30-Sep
Watermelons	15-May	30-Sep

Both the Begin Growth and End Growth dates vary across Pennsylvania, with shorter growing seasons occurring in the higher elevations and northern sections of the state. In addition, End Growth dates vary greatly due to the grower's farm business plan. If the grower is producing for a cannery or production facility (one harvest at peak production period) the "end-of-irrigation" will be different from the grower seeking to take fresh produce to a local market each week. In addition, some perennial crops need to grow and develop root/plant structure after the fruit production period in preparation for next year's crop.

The dates shown in Table 4.3 were the dates used as input to the NRCS IWRpm software to generate the Net (Seasonal Irrigation) and Total Water Depth Needs (Seasonal ET) data summarized in Tables 4.1 and 4.2. The results from this program are greatly influenced by the length of the growing season.

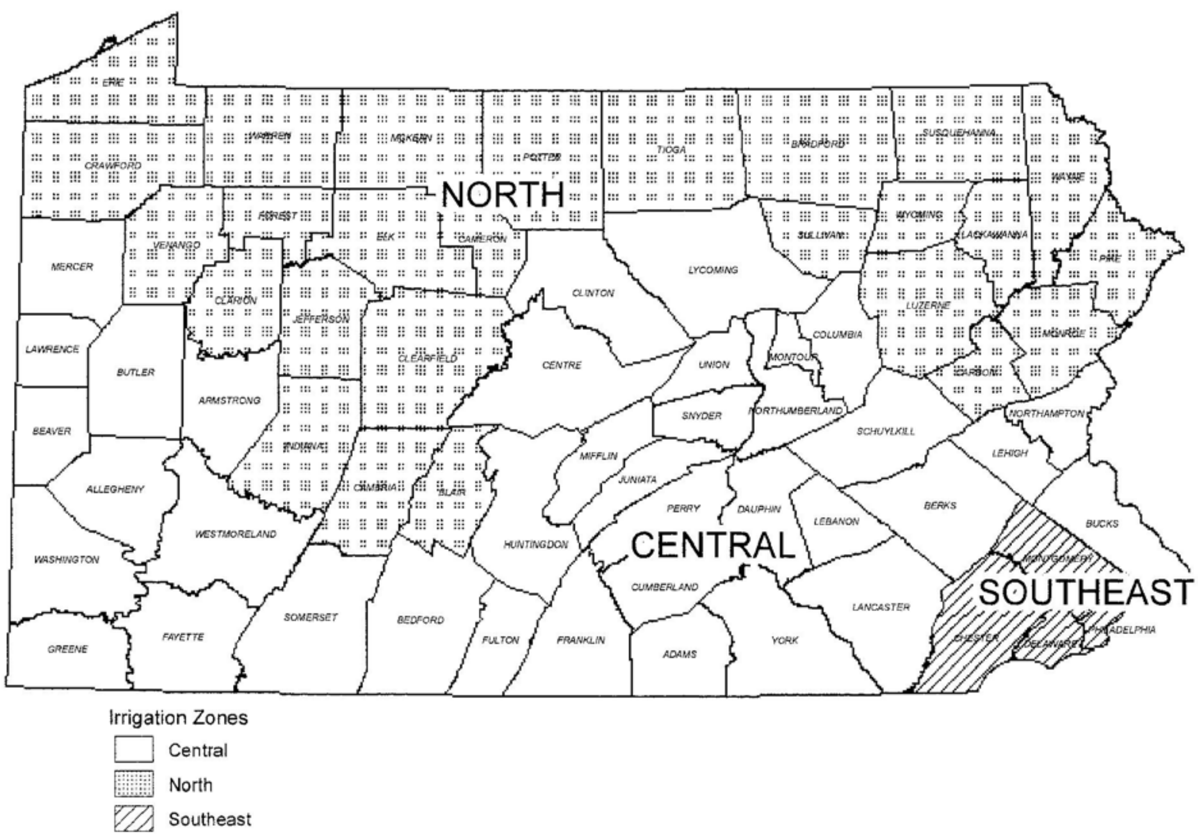
(g) Net Water Depth (Seasonal Irrigation) Needs of Each Crop

Earlier guidance was provided on what total seasonal water needs can be expected for various crops. The remaining, and most difficult, question for an irrigator, or irrigation system designer, to answer is "When considering the water contribution expected from natural rain, how much additional water will the irrigator need to provide via irrigation to produce a maximum crop?" The water added by natural rain is variable from day to day, week to week, month to month, year to year.

A Penn State University Extension Irrigation Specialist has summarized the need for irrigation in Pennsylvania by indicating that during an average ten-year period, growers will produce a good crop, or better, five out of every ten years without irrigation, they will produce a marginal or very limited yield three out of every ten years without irrigation, and two out of every ten years, the yield will be near zero.

To provide guidance to the question of what depth of irrigation water will probably be needed to elevate crop yields to the "good" or "better than average" level on a sustained annual basis, it is necessary to statistically evaluate the historical rainfall record in various locations across Pennsylvania. In addition, other climatic parameters, such as temperature, humidity, and cloud cover must also be evaluated as a function of location within the state. When all of these crop production factors are evaluated, it is possible, using the NRCS IWRpm software version 1.1 (2006) program, to estimate the Net Water Depth (Seasonal Irrigation) needed to grow selected crops in Pennsylvania. Because the program takes into account over 100 years of rainfall history at each of the 72 Pennsylvania weather stations as well as the available temperature, humidity, and cloud cover records, it is possible to present the Net Water Depth Needs for each selected crop at each weather station. It was this advanced analysis, that resulted in Pennsylvania being divided into three climatic regions; North, Central, and Southeast (see Figure 4.2). A more complete description of the NRCS IWRpm software is given in Appendix A.

Figure 4.2 Climatic Regions of Pennsylvania



The Net Water Depth Needs for the selected crops in each climatic region is given in Tables 4.1 and 4.2. The Net Water Depth Needs for the selected crops in each climatic region are given for years with "Normal" rainfall (Table 4.1) and for the years that are "Dry" (Table 4.2). The Normal years, Table 4.1, are for 50% chance of occurrence, effective precipitation will be equaled or exceeded one out of every two years. The Dry years, Table 4.2, are for years with a 20% chance of occurrence precipitation and will be equaled or exceeded two out of every ten years. The Net Water Depth Needs are given for each month of the growing season and summed to yield the growing season total net water depth needed (seasonal irrigation).

It should be noted that the Net Water Depth Needs given in Tables 4.1 and 4.2 are only estimates based on long-term averages of natural precipitation and other climatic parameters. These values may be helpful when estimating the volume of irrigation water that may be needed if irrigation is adopted and implemented. These values are the estimates of what volume of irrigation water a grower will need to properly supplement natural precipitation with the planned irrigation system. The decision as to using Normal, Dry, or other basis should be based on available irrigation water supply and the degree of drought risk the grower is willing to accept.

The shaded cells in the net water needs of each crop section of both Table 4.1 (Normal) and 4.2 (Dry) shown in columns 3 to 10 of each table represent the specific month with the largest net water need and the estimated value of that monthly net water need.

(h) Summary of Irrigation Water Volume Needs
The estimated water needs for various crops grown within the three climatic regions of Pennsylvania are provided to help growers and system designers estimate the volume of water that might be needed to provide the necessary irrigation water for specific crops. The following example demonstrates how these data can be used.

Example 4.1. A grower in Dauphin County wishes to irrigate a 7-acre field of tomatoes. Use the data provided in this Tables 4.1 and 4.2 to estimate how much irrigation water this grower may need to have a successful tomato crop, year after year.

Solution:
Total Water Depth needed to grow the tomato crop, assuming the tomatoes are transplanted on May 1st and harvest through September 30th (Table 4.3) will be, from Table 4.1, 23.4 inches of water (tomatoes in the central region, right-hand column). This depth of water includes both the water applied by natural precipitation and any additional water applied via irrigation. In a year when there is essentially no rain during this growing season, the grower will need approximately 164 ac-in, which is equivalent to 13.7 ac-ft or 595,000 cubic feet or 4.4 million gallons of irrigation water to grow these tomatoes over 7 acres.

Net Water Depth needed to grow the tomato crop, assuming the tomatoes are transplanted on May 1st and harvest through September 30th (Table 4.3) will be, from Table 4.1 (tomatoes in the Central region, Seasonal Irrigation third column from the right), 11.8 inches during a Normal year or 13.3 inches during a Dry year (Table 4.2, tomatoes in the Central region, right-hand column). Converting these depths to other units, reflecting the 7-acre field size, yields:

Normal Year: 11.8 inches = 83 ac-in, 6.9 ac-ft, 300,000 ft^3, or 2.2 million gallons of irrigation water.

Dry Year: 13.3 inches = 93 ac-in, 7.8 ac-ft, 340,000 ft^3, or 2.5 million gallons of irrigation water.

Therefore, during a growing season of normal rainfall, the grower can expect to need at least 6.9 ac-ft of irrigation water available for application to this field of tomatoes. Statistically, this would provide irrigation relief for 8 out of 10 years. If the growing season is drier than the driest 20% of the years, the grower can expect to need at least 7.8 ac-ft of irrigation water available for application to this field of tomatoes. Should it be an extremely dry year (essentially no rain during the entire growing season), the grower can expect to need at least 13.7 ac-ft of irrigation water available for application to this field of tomatoes. Placed in the context of a grower desiring to implement irrigation for these tomatoes, the grower should plan to have between 7 and 8 ac-ft of water available for irrigation of this 7-acre field of tomatoes. It is important to note that the above estimated Net Water Depth needed is the amount of water that the producer needs to ensure is available at the farm either via pumping from groundwater or extraction from an on-farm pond or adjacent reservoir or stream. No attempts should be made to install any irrigation system unless the seasonal availability of the design water is ensured.

(i) Auxiliary Water Requirements

In addition to crop evapotranspiration water requirements, irrigated water can also be used to meet special needs of crops. In Pennsylvania, sprinkler irrigation has been used for frost protection on blueberries, orchards and strawberries. Sprinkler systems are also used for crop cooling. Chemicals (fertilizers, pesticides, etc.) may also be applied through sprinkler or microirrigation systems. Applications need to be timed and incorporated into the irrigation scheduling program to prevent over-irrigating, leaching, and runoff.

(i.1.) Frost Protection

Sprinkler irrigation frost protection has been used to protect fruit trees, strawberries, and other vegetable and fruit crops. Frost protection requires that the irrigation system have enough capacity to apply water to the entire cropped area with a fine mist of water, (application rates should range from 0.1 to 0.2 inches/hour). Irrigation for frost protection utilizes the latent heat of fusion released when water changes from the liquid form to ice. The water is applied as a fine spray and the latent heat of fusion is released when the water freezes on the plant surface. The heat thus released maintains ice temperature around 32 °F. The ice acts as a buffer against cooling of plant surfaces by radiation or contact with cold air. The process is effective only so long as the water application and subsequent ice formation continues. Not all of the heat is retained by the ice. Some is lost to cold air in contact with the ice, and some is lost to evaporation and sublimation at the water-ice surface. Properly designed and operated irrigation systems can provide protection for certain crops to temperatures as low as 15 °F. Reports indicate that celery has been protected to 15°F, strawberries to 16°F, tomatoes to 26°F, blueberries to 24°F, peppers to 21°F, and cherries to 23°F. The rate of water application for frost protection depends on the air temperature. As the air temperature drops, more water must be applied to provide protection. The degree of crop frost protection available and the optimum sprinkling rates to be used are a function of the crop's resistance to cold air temperatures, stage of growth, humidity, wind speed, and the design and operation of the system. Table 4.4 gives recommended application rates for strawberries.

Table 4.4 Recommended Frost Protection Application Rates for Strawberries

Air Temperature °F.	28	26	24	22
Application Rate (in/hr.)	0.08	0.10	0.125	0.20

System Operation – The frost protection system should be turned on when air temperature at the plant level reaches 34 °F. An alarm system consisting of a thermo-switch set in the field at the plant level and wired to an alarm that will notify the operator when to turn the irrigation system on.

Sprinkling should continue until the ice has melted loose from the plants. If the water supply is cut off prior to this time, the supply of heat is also cut off, and sublimation will reduce the temperature of the ice surface to the wet bulb temperature if there is sufficient wind. In dry air, the wet bulb temperature may be several degrees below the dry bulb or air temperature, and if the sublimation process continues over a period of time, the temperature of the entire mass of ice and plant will approach the wet bulb temperature. It is, therefore, necessary to continue application of water until the wet bulb temperature is above the critical temperature of the plant.

Frost protection with irrigation works best on low-growing crops, such as strawberries. The weight of the accumulated ice may often damage tall-growing vegetable plants and fruit trees.

Sprinklers – Single-nozzle low-flow-rate sprinklers, designed especially for frost protection, are slightly different from regular sprinklers in that they have special bearings and low-tension arm springs or speed washers for faster rotation. Sprinklers should rotate 1 to 2 times a minute for adequate frost protection. Operating pressures in the high side of the manufacturer's recommended pressure range for the particular sprinkler should be used to obtain both good coverage and finer water droplets desirable for frost protection. Sprinklers should be spaced so the spacing between sprinklers is no greater than the sprinkler's wetted radius; thus, maximizing the sprinkler's ability to apply water uniformly to the crop being protected. Clean water is also a must, since foreign material in the water can easily clog the small sprinkler orifices.

(i.2.) Fertilizer and Chemical Application

Using irrigation water as the carrier for fertilizers, herbicides, and other chemicals used in crop production is a practice that is increasing in popularity and acceptance. Savings in labor and time, and in many instances a more efficient fertilization program can be achieved through fertigation.

Fertilizers – Fertilizers can be applied with irrigation water, regardless of the methods used for water distribution. Injector pumps and metering devices designed to inject fertilizer solutions into the irrigation system is considered an integral part of practically all sprinkler and microirrigation designs offered on today's market. Field tests and research projects have established that nitrogen mechanically applied before planting is often lost to the plant through leaching by rains or early irrigations that carry the nutrient to depths below the root feeder zone. This supports the concept of "spoon feeding" a growing crop by applying smaller amounts of fertilizer at regular irrigation intervals throughout the season instead of one or two applications. These same tests have further established that applying nitrogen with irrigation water is more effective on sandy soils, and just as beneficial on fine-textured soils as using mechanical applicators.

The danger of polluting underground aquifers or surface streams with leached or runoff water laden with nitrates is alleviated if the fertilizer is applied in amounts that can be readily absorbed by the growing crop while the fertilizer is still in the upper part of the root zone. This danger is more likely in coarse textured, sandy soils than in soils having fine textures, but can be of concern on any farm.

Nitrogen fertilizers can be applied with irrigation water, although some are not recommended for use in certain types of distribution systems. Solutions of ammonium nitrate, ammonium sulfate, and urea will not cause corrosion or encrustation of aluminum pipe and fittings in any irrigation system. They are recommended for sprinkler and other type systems using aluminum pipe.

Anhydrous and aqua ammonia should not be used with sprinklers.

The task of putting the proper amount of fertilizer into the irrigation water has been minimized within recent years by the development of a large number of metering and injecting pumps. These units can be driven by a belt from a pump motor or drive shaft, by directly connected electric motors or by air-cooled engines. They are capable of measuring and injecting fertilizer solutions accurately and uniformly into any irrigation system.

Fungicides – Several tests on a wide variety of crops have been made in the last few years involving the application of fungicides with sprinkler systems. Many chemical manufacturers recommended that the foliage of the crop be thoroughly wet in order for the fungicide to be effective. Sprinkler systems of any type are the ideal distribution and application apparatus. A more uniform distribution pattern over the field has often been attained with sprinkler systems than with aerial applications.

Herbicides – Applying herbicides via sprinkler irrigations systems is now almost an accepted practice in many areas, and operators have reported a more even weed kill pattern than with other application methods, while saving labor costs. Reducing the number of trips over the field with equipment during the growing season is also a benefit.

It should be remembered that the success of any combination program involving fertilizers, herbicides, or other agricultural chemicals is directly hinged to applying the proper amount of a particular substance at the right time. The mixture must be correct, and this can only be done by knowing exactly how much water is being applied to the crop's root zone.

Most fertilizer dealers can furnish charts to help the irrigator determine how many gallons per hour of solution should be added to the irrigation system, and their advice can be confidently followed.

Injector Pumps – Any irrigator using an electric-powered metering-injecting pump for chemical application should be certain that it is wired so that the injector pump will cease operation if the water pump stops. If the unit is belt driven from the pump or its power unit, this safety measure has been taken care of at installation. In addition, there should be **backflow prevention** on the main line between the injection point and the water source to prevent accidental back flow of chemical laden water into the water source. Practically all manufacturers of these devices are producing a range of capacity sizes. Selecting a pump to do the required job becomes a catalogue exercise at the dealer's place of business.

Some injector pump models are constructed with dual pumps, permitting the injection of more than one chemical into the water supply with the same unit.

A uniform chemical mix can be expected if the solution is added at any point near the beginning of the irrigation system. Injecting chemicals just after centrifugal pumps, on the pressure side, provide satisfactory results. Most metering pumps are high pressure, positive displacement types, and deliver the chemicals into the pipeline at pressures higher than the water therein.

Phosphates – If it is desired to apply ammonium polyphosphate through an irrigation system, the phosphate will move to the proper root depth in sandy soils, but deep penetration in clayey soils is not likely.

(j) Water Sources
The sources of irrigation water most common in Pennsylvania are wells, farm ponds for temporary storage of surface runoff, streams, and public water supplies.

Wells
The daily yield or supply of water from a well depends upon the kind of aquifer or water-bearing geologic material in which the intake part of the well is placed. The size and diameter of the well casing also affects the rate and efficiency of water withdrawal.

It is difficult to predict the amount of water that can be obtained from a well that is drilled at any given location. Consultation with a hydrogeologist is recommended.

Streams
A stream must have sufficient, continuous flow during drought periods when irrigation is most needed. The stream flow should be measured during a drought period to determine if the flow is adequate. Stream data available from the U.S. Geologic Survey may be checked to determine flow records on gaged streams. Permits will be required for most stream withdrawals.

Farm Ponds
A farm pond with no certainty of inflow during the irrigation season must have a storage capacity large enough to meet crop needs for the season plus evaporation and seepage losses. The amount of water required

will vary according to the needs of the different crops. A farm pond can be used in combination with a stream to provide an adequate volume of irrigation water where the stream has adequate base flow to refill the pond between irrigations.

Public Water Supplies

Public water supplies are more likely to be used when the volume of water required is small and the pressure requirements are compatible with the local water system. Therefore, small sprinkler and microirrigation systems may be economically supplied by a public water system. If a public water system is considered as a supply, the requirements of the system owner must be met before using the system as an irrigation source. A common concern and requirement of the system owner will be backflow prevention.

Chapter 5 Irrigation Method Selection -- 652.0505 PA State Supplement

(a) General

The purpose of this chapter is to provide necessary planning considerations for selecting an irrigation method and system. This chapter describes the most widely used irrigation methods and systems in Pennsylvania along with their adaptability and limitations. Also refer to National Engineering Handbook (NEH), Part 623, and National Irrigation Guide, Part 652, Chapter 5.

(b) Methods and Systems to Apply Irrigation Water

The two basic irrigation methods used in Pennsylvania are sprinkler and microirrigation (drip).

Sprinkler – A majority of the irrigation in Pennsylvania consists of the sprinkler type. This method applies water through a system of nozzles (impact, gear driven sprinkler, or spray heads) with water distributed to the sprinkler under pressure through a system of surface or buried pipelines. Sprinkler heads and nozzles are available in a wide variety of sizes and can apply water at rates less than 0.1 inches/hour to more than 2 inches/hour. Sprinkler irrigation systems include the following: Solid Set, Hand-move Laterals, Center Pivot, and Traveling and Stationary Guns. Low Energy Precision Application (LEPA) and Low Pressure in Canopy (LPIC) systems are included with sprinkler systems because they are adaptations of center pivot systems.

Micro (Drip) – Water is applied through low-pressure, low volume discharge devices (drip emitters, line source emitters, micro spray heads, bubblers, etc.). These are supplied by small diameter surface or buried pipe, tubing, hose or tape. There is an emitter close to the base of each plant. Water trickles or drips out of the emitter and soaks into the ground. Several emitters may be placed around the base of the tree for orchard use. It is a highly efficient system, because water is applied directly to the crop root zone. Micro or drip irrigation is adaptable to many specialty fruits and vegetables grown in Pennsylvania and is increasing in acreage each year, replacing many lower efficiency sprinkler systems such as the traveling gun systems. This is resulting in a water and energy savings along with improved yield quality and quantity.

Each irrigation method and system have specific site applicability, capability, and limitations. Broad factors that should be considered are:

- crops to be grown
- topography or physical site conditions
- water supply
- climate
- energy available
- chemigation
- operation and management skills
- environmental concerns
- soils
- farming equipment and practices
- costs
- plans for expansion

(c) Site Conditions

Table 5.1 displays the site and other local conditions that must be considered in selecting an irrigation method and system. Other factors to consider include:

- Farm, land and field – Field size(s) and shape, obstructions, topography, flood hazard, water table, and access for operation and maintenance.

- Energy and pumping plant – Type, availability, reliability, parts and service availability, and pumping efficiency.
- Environmental effects – Quantity and quality of surface and groundwater.
- Water Availability – Water rights, allocations, and priority.
- Cost – Availability of funds for improvements
- Sociological and Managerial Factors (i.e. grandpa and dad did it that way) – Available technical ability and language skills of laborers, Time and skill level of management personnel

Table 5.1 Site Conditions to Consider in Selecting an Irrigation Method and System

Crop	Soil	Water	Climate
Crop grown & rotation	AWC	Quality	Wind
Water requirements	Infiltration rate	Quantity	Rainfall depth
Height	Depth of soil	Reliability	Frost conditions
Cultural practices	Drainage, surface, subsurface	Source	Humidity
Pests	Condition	Availability	Temperature extremes
Tolerance to spray	Uniformity		Rainfall frequency
Toxicity limitations	Stoniness		Evaporation, ET
Allowable MAD level	Slope		Solar radiation
Frost protection	Surface texture		
Crop cooling	Profile texture		
Disease & control	Structure		
Crop quality	Fertility		
Planned yield	Temporal properties		

(d) Selection of Irrigation Method and System

In selecting an irrigation method and system, various factors must be considered. Primary concerns in Pennsylvania include availability of water supply, adaptability to the crops grown, cost effectiveness of the system, level of management, and labor requirements.

Tables and guidance on how to estimate the typical life and annual maintenance for irrigation system components are available in Table 5.2 of the NEH, Part 652.

(e) Adaptability and Limitations of Irrigation Methods and Systems

(e.1) Sprinkler Systems

Solid Set, Permanent – All pipe (laterals and mains) and sprinklers are placed in the field and remain there until the crop is harvested. Usually one or two laterals are run as a set controlled by valve(s) at the end of each lateral. The entire field (all laterals) can be run at once for frost protection.

- Adaptable to irregular fields and rolling terrain.
- Low labor requirement.
- Allows for light applications at frequent intervals.
- Adaptable to irrigating blueberries, brambles, container nursery, orchards, and trees.
- Entire system can be operated at one time for frost protection and crop cooling at low application rates < 0.15in/hr.
- Easily automated.
- High initial cost versus hand move laterals systems.
- Wind drift and evaporation problems with low application rates < 0.15in/hr.

Hand Move Lateral, or Portable – Main is located along one side of the field. Only enough lateral pipe and sprinklers are laid to support one set. Between each set, the lateral(s) are picked up and hand moved to the location of the next set.

- Adaptable to irrigating vegetable, orchard, berries, and potatoes.
- Lowest initial cost.
- Adaptable to irregular fields and rolling terrain.
- Lower efficiency then solid set.
- Highest labor requirement.

Center Pivot – Consists of a single lateral attached to a pivot point, usually in the middle of the field. The lateral is suspended on wheels and driven by electric or water power. The system can be programmed to make a full, or part, rotation as desired. One rotation irrigates the entire field.

- High uniformity and high efficiency with low volume and low-pressure nozzles on drops.
- Adaptable for irrigating corn, potatoes, vegetables, field crops, and alfalfa hay.
- Easily automated.
- Low labor requirement.
- High initial cost.
- Irrigates circular area and corners with end guns or corner arms.
- High application rates near the pivot center may exceed the soils infiltration rate.
- Drive wheels may create ruts in some fields.
- Operates best on topography with slopes <10% but have been successfully adopted on more undulating or rolling land.

Stationary Gun – One, large bore sprinkler is mounted on a stand connected to the water supply via a flexible pipe. This single sprinkler is operated as one set. At the end of its run-time, the gun can be moved to another location.

- Adaptable for irrigating corn, potatoes, vegetables, alfalfa and field crops.
- Adaptable to irregular shaped fields.
- Moderate costs.
- Less labor then hand move laterals.
- Require high operating pressures and high-power pumping units.
- Wind seriously affects the distribution pattern, causing non-cropped areas to be wetted.
- Low efficiency due to high evaporation and runoff potential.
- Difficulty in locating the sprinkler to yield good uniformity of water distribution.

Traveling Gun – One, large bore sprinkler is mounted on a mobile cart and connected to the water supply via a flexible pipe. As this single sprinkler passes through the field (one set) a strip of the field is irrigated. At the far end of the field, the gun must be moved to an adjacent location where the next set can be irrigated.

- Adaptable for irrigating corn, potatoes, vegetables, alfalfa and field crops.
- Adaptable to irregular shaped fields.
- Moderate costs.
- Less labor then hand move laterals.
- Require high operating pressures and high-power pumping units.
- Towpaths are required in the cropped area.
- Wind seriously affects the distribution pattern, causing non-cropped areas to be wetted.
- Low efficiency due to high evaporation and runoff potential.
- Difficulty in locating the sprinkler paths to yield good uniformity of water distribution.

(e.2) Microirrigation (drip)

- Highest potential application efficiency - low runoff and low evaporation losses.
- Highest design distribution uniformity.
- Spoon feeds water directly to root zone.
- High yields and quality.
- High efficiencies result in lower wasted water, which enables smaller water supplies to be utilized.
- Requires less water than overhead sprinkler systems due to greater system efficiencies.
- Pipe network can be smaller than high pressure/flow systems and therefore less costly.
- Disease control is high since leaves are not wetted.
- Ability to fertigate through system.
- Extensive automation is possible.
- Field operations can continue while irrigating.
- Adaptable to irregular shaped fields.
- High degree of filtration and pressure regulation required.
- Higher maintenance and management skills are required.
- Requires good quality water supply and properly designed filtration system to prevent emitter clogging.
- May require water treatment through chlorination to kill algae, bacteria, or precipitate iron out of water supply.
- Rodent and insect damage to plastic tape/hose can be a problem.
- Not adaptable to frost protection.
- Initial investment and annual costs are higher than most other methods.

Point Source Drip Emitters –Point-source emitters are usually installed to drip irrigate trees or other similarly managed plants. Single emitters may be inserted directly in a supply lateral or can be connected at the end of a micro-tube (spaghetti). The emitter discharges precise volumes of water to the soil beneath the emitter. These emitters can be either non-pressure compensating emitters (the flow rate changes with the water pressure in the supply pipe) or pressure compensating emitters (the flow remains nearly constant regardless of the pressure in the supply pipe).

- Adaptable for irrigating orchards, berries, and vineyards.
- With pressure compensation can be operated on uneven topography and odd shaped fields.
- Application uniformity not affected by wind.

Line Source Emitters –Line-source emitters consist of drip tubing with small plastic emitters imbedded at set intervals ranging from 6 to 60 inches. Each emitter discharges precise volumes of water to the soil beneath the emitter. These emitters can be either non-pressure compensating emitters (the flow rate changes with the water pressure in the supply pipe) or pressure compensating emitters (the flow remains nearly constant regardless of the pressure in the supply pipe).

- Best adaptable to irrigating fresh vegetables and row crops.
- Application uniformity not affected by wind.
- Not suitable on steep or uneven topography.

Micro Spray/Sprinkler –This is a broad category of water application devices ranging from small micro spray heads, small sprinkler heads, bubblers, and other spray-oriented devices. These devices are supplied by small diameter surface or buried pipe, tubing, or hose. Micro spray head are adaptable to many specialty fruits and vegetables grown in Pennsylvania.

- Adaptable for irrigating orchards, nursery trees and container stock.
- Provides frost control in orchards, vineyards and small fruits.

- Application uniformity can be affected by wind.
- Higher evaporation losses.

Guidance on how various factors affect the adaption and operation of various irrigation methods and systems are available in Chapter 5 of the NEH, Part 652.

Chapter 6 Irrigation System Design -- 652.0605 PA Supplement

(a) General

A properly designed irrigation system addresses uniform irrigation application in a timely manner while minimizing losses and damage to soil, water, air, plant, and animal resources. The design of an irrigation system matches soil and water characteristics with water application rates and application depths to assure that water is applied in the amount needed at the right time and at a rate at which the soil can absorb the water without runoff. Physical characteristics of the area to be irrigated must be considered in locating the pipes and spacing the sprinklers or emitters, and in selecting the type of mechanized control system. The crop ET demands and the available water storage in the crop rooting zone will dictate the size of the water supply and the pump and pipe sizes required.

Key points in designing an irrigation system include:

- The irrigation system must be able to deliver and apply the amount of water needed to meet the total crop-water requirement.
- Application rates must not exceed the maximum allowable intake rate for the soil type. Application rates that are too large will result in water loss, soil erosion, and possible surface sealing.
- Sprinkler and emitter flow rates and spacing along with the water management decisions dictate the pipe and pump sizes.
- Soil textures, available soil water holding capacity, and crop rooting depth must be known for planning and designing the irrigation system.
- The water supply, capacity, and quality need to be determined. If the water supply is the limiting factor, the area to be irrigated and how the system is managed may be altered.
- Climatic data – precipitation, wind velocity, temperature, and humidity must be addressed.
- Topography usually dictates how the pipe delivery system is laid out. It could also affect the type of system to be selected.
- Farmer’s preferences in irrigation methods, available operation time, farm labor, cultural practices, and management skills must be considered and incorporated into the system design.
- The most opportune time to discuss and review problems and revise management plans that affect design and operation of the irrigation system is during the planning and design phase. The physical layout of a system can be installed according to data from this guide. Operational adjustments then must be made for differing field and crop conditions.

Minimum requirements for the design, installation, and performance of irrigation systems should be in accordance with the standards of the Natural Resources Conservation Service, the American Society of Agricultural and Biological Engineers, and the National Irrigation Association.

Material and equipment used must conform to the specifications of the Natural Resources Conservation Service Technical Guide Standards.

(b) Chapter Layout

This chapter contains several major sections. The first is the design procedure including the theory behind design decisions. The next section describes how solid set and portable sprinkler irrigation systems should be designed. This is followed by several key elements related to big guns and center pivot irrigation systems. The last portion of this chapter is devoted to microirrigation systems and how they should be designed.

(b.1) Irrigation System Design Procedures and Theory; Section (c)
Section “c” presents the design procedures, the theory behind each of these procedures, and the equations, figures, and tables needed to design an irrigation system with a focus on portable and solid set sprinklers systems. These include the following fundamental decision-making procedures and the basic fluid mechanics controlling each of the major design steps.

- Soil and crop-based design limitations; Design Depth and Irrigation Interval
- How to make the design-controlling irrigation system management decisions.
- Selecting the spacing between sprinklers and laterals.
- Sprinkler performance and selection procedures.
- System pipe layout
- Pipe types and selection guidelines.
- Pipe sizing procedures.
- Determining pressures and pump energy requirements.
- Pump selection
- Power unit sizing.

A complete example showing the design procedure and how each design step should be applied is given in Appendix D.

(b.2) Sprinkler Irrigation Systems; Section (d)
Section “d” presents design relevant information that a designer and grower need to properly understand, operate, and maintain stationary guns, traveling guns, and center pivots.

(b.3) Microirrigation Systems; Section (e)
Section “e” is devoted to understanding the various types of microirrigation systems. A design example of a field to be irrigated using line-source emitters is given in Appendix E. A design example of a field to be irrigated using point-source emitters is given in Appendix F. The last section presents several notes relating to how using micro sprinklers (spray heads) may alter point-source drip designs.

(b.4) Solid Set or Portable Systems

(b.4.a) Solid Set Systems
Solid set irrigation systems consist of enough laterals and sprinklers so that either; (a) the entire field can be irrigated at one time, or (b) lateral pipe and sprinklers do not need to be moved to change the irrigation application area (set) from one location to another. Thus, an entire irrigation cycle can be accomplished without moving pipe or sprinklers.

Solid set sprinkler systems consist of either an above ground pipe system (aluminum pipe) or a permanently buried pipe system (plastic pipe). Solid set systems are placed in the field at the start of the irrigation season and left in place throughout the entire growing season. If the pipe is buried, the pipe will remain in the field for many years.

To irrigate the field, one or more zones (or sets) of sprinklers are cycled on or off with control valves located at the mainline. Opening and closing of valves can be manual or programmed electronically with a timer clock. Solid set systems can be easily automated. Application efficiencies can be 60% –85%, 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, and chemical application.

(b.4.b) Portable Systems
Portable irrigation consists of just enough lateral pipe and sprinklers placed in the field to facilitate irrigation of one set. At the end of each set, the irrigation system is turned off and the lateral pipe and sprinklers are moved, often by hand, to the location for the next set.

The major advantage of a portable system is reduced cost because enough pipe and sprinklers are only purchased for one set location. The major disadvantage is the cost of manual labor needed to move the lateral and sprinklers between each set. Application efficiencies can be 60 – 75% with proper management.

A complete example showing the design procedure for a portable sprinkler system including how each design step should be applied is given in Appendix D.

(c) Irrigation System Design Procedures and Theory

(c.1) Soil and crop-based design limitations – Design Depth and Irrigation Interval
The place to start any irrigation system design is by focusing on two questions; "How often should the irrigation system apply water?" and "How much water should be applied during each irrigation?" The answer to these two key questions is rooted in the AWC, Table 2.1, in the crop's effective root depth, Table 3.2, the maximum rate at which the crop takes water from the effective root depth (ET), and the efficiency of the proposed irrigation system, the water application efficiency (WAE).

From these basic parameters, two fundamental design parameters are computed. The first of these is a measure of how long it will take the crop in question to use half (50%) of the root-zone AWC, which is called the irrigation interval (II) or the time between irrigations when there is no natural precipitation. The time period required for the crop to transpire half (50%) of the plant's effective root depth AWC, the irrigation interval (II) is:

$$II = \frac{0.5(AWC_{RZ})}{ET} \tag{6.1}$$

where AWC_{RZ} is the available water capacity in the effective root depth of the crop to be irrigated and ET is the maximum, or design, crop ET rate in inches/day (usually the expected peak daily ET during the growing season). The available water capacity, in inches of available water per effective rooting depth for each of the Pennsylvania soils is given in Table 2.1. These available water capacities were established for the depth of the effective root depth of each soil between field capacity and the wilting point (see Figure 2.1). In Equation 6.1, there is a 0.5 in the numerator. This 0.5 value represents 50% or half and by multiplying the AMC_{RZ} times 0.5, calculates 50% of the available water in the effective root depth (between field capacity and the wilting point). The 50% is an average MAD for Pennsylvania crops, a more specific reference is found in NEH 652 Table 3-3.

The second irrigation design parameter required for an irrigation system is the design depth. The depth of water that needs to be applied to a field, during each irrigation application, is commonly referred to as the design depth (DD) and is:

$$DD = \frac{0.5(AWC_{RZ})}{WAE} \tag{6.2}$$

The numerator is the same as was used in Equation 6.1. The WAE is the water application efficiency of the irrigation operation. Well-designed sprinkler irrigation systems usually have WAEs of about 70-85% (use of 70% is recommended for Pennsylvania). In other words, 30% of the water pumped from the source will not get to the crop effective root depth where it can be used by the plants. The following examples illustrate how DD and II can be computed for typical conditions.

Example 6.1: Determine the design depth and irrigation interval for potatoes, with an 18-inch effective root depth, growing in a Clymer soil. The water application efficiency for a sprinkler irrigation system is 70% and the design daily ET rate is 0.2 in/day.

Solution:

1. To determine the design depth, the AWC in the 18-inch deep effective root depth can be read from Table 2.1 as 2.2 inches. Substituting these values and WAE = 0.7 into Equation 6.2 yields a DD of 1.6 inches.

2. To determine the irrigation interval, note that the AWC is the same as was used for the DD calculation. Substituting the AMC_{18} = 2.2 in and the ET = 0.2 in/day into Equation 6.1 yields II of 5.0 days.

For this sprinkler irrigation system, the designer needs to think in terms of applying 1.6 inches of irrigated water to the crop every 5 days. Of the 1.6 inches of water taken from the water source, about 1.1 inches will make it into the effective root depth where it can be used by the crop. The remaining 0.5 inches of water may be lost to runoff, be intercepted onto the plants and evaporate, be lost to pipe leakage, or evaporate from the applied water as it flies through the air from the sprinkler to the crop canopy.

The design depth and irrigation interval are the foundational parameters upon which a supplemental agricultural irrigation system design should be based. The design depth is the depth of water that should be applied each time the irrigation system is turned on. The irrigation interval is the number of days it should take the crop to evapotranspire the applied water from the effective root depth, therefore the irrigation interval is a measure of the number days between irrigations; assuming no natural precipitation.

(c.2) Design-Controlling Irrigation System Management Decisions.

This section focuses on making the irrigation system wide design-controlling management decisions. The irrigation system delivery apparatus should be designed assuming there will be no natural precipitation. Managing an irrigation system, taking into account the contribution of natural rain, will be covered in Chapter 9.

Based on the design depth, DD, and the irrigation interval, II, and the specific land area to be irrigated, it is necessary to develop the management parameters upon which the irrigation system will be designed and managed in the absence of natural precipitation. This is often the most difficult part of an irrigation design and one most beginners choose to not consider seriously. At issue is essentially every parameter that will determine the size and cost of all system components including sprinklers, pipes, pump, and power unit; the whole system. These decisions dictate which water application devices (sprinklers) should be used in the design. In addition, each soil has a limiting water intake capacity that must be incorporated into the design decisions. With all of this is the desire to develop the lowest cost system and a system that can be easily managed on a day to day basis by the irrigation decision maker.

To begin this process, it is necessary to define the parameters and the relationships between these parameters. It is also necessary to define several constraints. This can be accomplished by making use of the following three relationships:

$$\text{Time/set: } T_s = \frac{DD}{A_r} \tag{6.3}$$

$$\text{Sets/day: } S_d = \frac{H_a}{T_s} \tag{6.4}$$

$$\text{Sets/cycle: } S_w = S_d(II) \tag{6.5}$$

where a “set” is the portion of the total field that is irrigated at any given time and T_s is the time required to apply the design depth, DD of water at the design application rate, A_r during any one set. The sets/day, S_d are the number of sets that can be completed during any working day with H_a hours available during each day for irrigation. The sets/day S_d, should be an integer so specific land parcels, or sets do not extend across more than one working day. The sets/cycle, S_w is the number of sets, or set areas or periods required to provide irrigation coverage of the entire field, or area to be irrigated, commonly called a cycle. Normally the cycle is established as the irrigation interval, II, but it is permissible to select cycle durations that are shorter than the irrigation interval. The importance of S_w is that the land area to be irrigated will be divided into S_w equal parts, therefore, S_w must be an integer, as should the set/day, S_d.

This discussion may seem unnecessarily complex. “Why do we need to split the field into little pieces for purpose of irrigation?” Or, “Why can’t we just irrigate the whole field at once?” Splitting a field into several small parcels, called ‘sets’ may be done for several reasons. The first is that it might be very expensive to purchase and operate an irrigation system large enough to irrigate the whole field at one time. The second reason has to do with possible sprinkler limitations as sprinklers do not apply water uniformly when the design application rate is below 0.20 inch/hour. A third reason might be a limited water rate/supply. These considerations will become clearer after sprinkler selection is presented in the next section.

Development of an appropriate management scheme depends on the incorporation of each of the limitations imposed by the grower or operator. These may include hours available for irrigation each day, H_a and days of the week when the crew does not work. Other considerations are the limitations imposed by the soil, such as maximum intake rate, irrigation interval, and design depth, and the irrigation sprinkler hardware, such as minimum acceptable application rate. The grower limitations need to be solicited from the owner/operator before an effort is made to develop these management parameters. The grower/operator desires must be honored if the owner/operator is expected to be pleased with the irrigation system.

The soil limitations are very important. If water is applied faster than the soil's maximum intake rate, see Table 2-1, some of the water will runoff where it can cause flooding, erosion or unwanted wetness. It is permissible to adjust the portion of the soil's AWC that is actively utilized for holding irrigated water. This is accomplished by adjusting the "0.5" MAD parameter in the numerator of Equations 6.1 and 6.2. Since plants generally are able to extract water held in the wetter half of the AWC more easily than the water held in the "dryer" half of the AWC, it is recommended that the maximum depletion level (MAD) parameter not be increased above 0.6. Decreasing the MAD is acceptable and often done.

There are limitations placed on an irrigation system by the availability of irrigation hardware. These limitations are evident primarily in the sprinklers available from manufacturers and pipe being available only in pre-determined sizes and lengths. If the design application rate is chosen to be too small it will be very difficult, if not impossible, to find a sprinkler that will throw water over a large enough area while having a small enough flow rate. As a rule of thumb, it is best if the design application rate chosen is kept larger than 0.2 in/hr. For some combinations of sprinkler spacing and discharge, it is possible to get good coverage when the design application rate is less than 0.2 in/hr. Good systems with application rates as low as 0.075 in/hr have been developed, but only for sprinkler spacings in the range of 30-45 ft. The application rate should be the designer's choice within the constraints of the soil's water flow properties.

It should be noted that the decisions made at this stage of the design will dictate much of the rest of the hardware and cost of the system. Having an operator select a small H_a value will increase the cost of the system. Selecting high application rates will increase the labor cost of the system.

Systematic application of Equations 6.3 to 6.5 generally results in the design parameters for the desired irrigation system. The best approach to using Equations 6.3 and 6.4 is to substitute Equation 6.3 into Equation 6.4 and rearrange the formula to solve for application rate, A_r as

$$A_r = \frac{S_d(DD)}{H_a} \tag{6.6}$$

In Equation 6.6, DD and H_a are known. The sets/day, S_d must be an integer. It is best to substitute S_d values into Equation 6.6 and solve for A_r values that could be implemented to create a meaningful design. Example 6.2 will be used to demonstrate and illustrate this procedure.

Example 6.2: A planned irrigation system has a DD = 1.6 inches (for Clymer soil and an 18-inch effective root depth) and an II = 5 days. The operator has specified that the irrigation system shall not be operated more than 12-hr/day during 7-day workweeks. Develop a list of the possible application rates and select one that will work well.

Solution: By substituting DD = 1.6 inches; H_a = 12 hr/day into Equation 6.6 for S_d = 1, 2, . . ., the following table was developed:

S_d	A_r
1	0.13
2	0.27
3	0.40
4	0.53
5	0.66
6	0.80

The limits imposed on the application rate are a minimum of 0.2 in/hr. (see discussing above). Based on Table 2.1, the design intake rate should not be greater than 0.7 in/hr. for Clymer soil. Therefore, selecting 6 or more sets/day is unacceptable because they yielded application rates greater than the soil's maximum intake rate. Also, because 1 set/day yields an application rate that is less than 0.20 in/hr., 1 set/day should be avoided. Thus 2, 3, 4 or 5 sets/day could be chosen. From the above table, it can be seen that if 2 set/day is selected the application rate will be 0.27 in/hr. to effectively utilize the 12 hr. /d available. Since smaller numbers of sets reduces the number of set changes, thus reducing the labor cost, 2 sets/day will be selected.

This irrigation system will be designed to apply a DD = 1.6 inches every 5 days at an A_r = 0.27 in/hr. which yields a T_s = 6 hr. or 2 set/day and 10 sets/II. Therefore, the field should be divided into 10 equal parts.

NOTE: If 3 sets/day had been chosen (A_r = 0.40 in/hr), the field would be divided into 15 equal parts.

(c.3) Selecting the Spacing between Sprinklers and Laterals

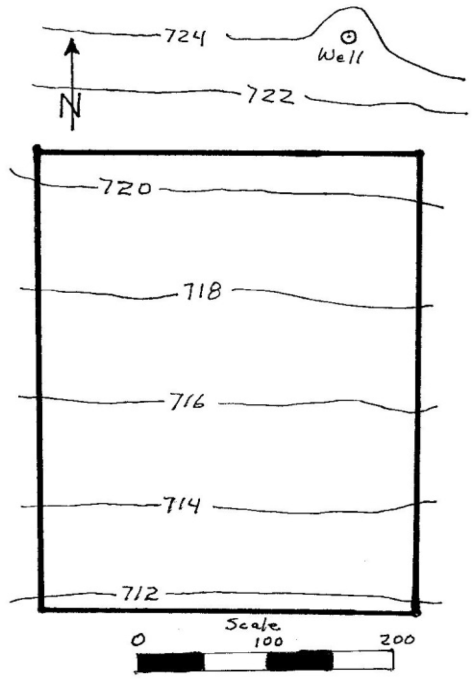
After determining the number of sets the field is to be divided into so the soil, crop and grower's limitations will be met, the task is to select or design hardware for the segments or sets of the field that will be irrigated at any given time. Remember sprinklers will distribute the water, but before specific sprinklers are selected to accomplish this application, the spacings between sprinklers and lateral pipes, that carry the water from the main distribution pipes to the sprinklers, must be selected. Selecting the location of the mains is not quite as important. It will come later.

The laterals are lengths of pipe that carry water from the main supply pipe to each sprinkler attached to that lateral. These laterals, each containing several evenly-spaced sprinklers, are usually laid out in the field parallel to one side of the field. Thus, to look at several laterals, each containing a number of sprinklers, should give an appearance of a square or rectangle with a sprinkler located on each corner of the square or rectangle. The distance between the laterals, L and the distance between the sprinklers on the laterals, S, define the sprinkler spacing. If S equals L the spacing is square. Generally, all laterals should proceed downhill from the main supply pipe or in some cases when downhill systems are not possible, the water may flow on the contour in the lateral pipes. Generally, laterals should not proceed uphill from the main as laterals running downhill benefit from the gained head pressure which acts to offset the pipe friction losses.

The number of laterals and sprinklers or the distance between laterals and sprinklers can vary within the limits of about 20 to 200 feet. Consideration should be given to the required operating pressures, the wetted diameter of the sprinklers, and the overlap required to get the required uniformity.

With some care and planning, it is often possible to make the distance between laterals, L, as multiples of the field width, perpendicular to the slope, and the number of sets per cycle. If the L spacing works out well, assume the spacing between sprinklers to be the same as L; a square spacing. If the field width, parallel to the contour, does not divide equally by L, try adjusting S upwards or downwards by 5 to 10 feet and see if a fit can be found. Selecting sprinkler spacings is common sense. One other consideration when choosing spacings is that pipe usually comes in 20-, 30-, or 40-foot lengths. If a spacing, such as 45 feet was chosen, pipe sections will need to be cut to make the spacing work. This can be costly, and it can get complicated. A good fit is all that is desired.

Figure 6.1 Example potato field



Example 6.3 A 300- by 400-foot potato field, see Figure 6.1, is to be sprinkler irrigated. The field is to be irrigated in 10 sets/cycle. Select an appropriate spacing between the laterals (L) and the spacing between the sprinklers (S) for this irrigation system.

Solution: The field is a rectangle. In addition, it should be noted that the field has a downward slope from north to south. Therefore, the laterals should be laid up and down the slope, running north to south. A good place to start is to divide the 300-foot field width by 10 sets to equal 30 feet between laterals.

Since the field's other dimension is 400 feet, the spacing between the sprinklers on each lateral could be 40 feet (400/10=). This yields a square 40' by 30' spacing where the 40 is the distance between the sprinklers on the lateral, S and the 30 is the distance between the laterals, L. To make the best use of the pipe and sprinklers and to maximize the uniform coverage of the field, the laterals and the sprinklers on each lateral are usually located a half-spacing from the edge of the field. This means there will be a small amount of sprinkler over-throw on to the areas adjacent to the field. If this over-throw is unacceptable, part-circle sprinklers should be considered.

Result: This means that one lateral will run during each set; or, 1/10 of the field will be irrigated during each set. This one lateral will have attached to it, 10 sprinklers, spaced 40 feet apart. At the end of the 6-hour set, the system will be shut-down, and the lateral will be moved (usually by hand) to the next position in the field. This new position will be 30 feet from the first set position and parallel to the first lateral position.

Alternate solution and discussion: It would have been okay to select an 80- by 60-foot spacing for this field. This would have created a system with only 5 set positions. If this choice had been made, the grower would have been able to irrigate the potato field in only 2.5 days, instead of 5 days. There are two reasons why this might have been a poor decision; (a) the 2.5-day irrigation period would yield a piping and pump that would be two times larger than the 5.0-day approach, essentially doubling the cost of the system, and (b) the 2.5-day choice yielded a spacing that was a rectangle with the sides of the rectangle being 20 feet different. This is about the maximum difference for a good distribution system. Rectangle spacing patterns are acceptable, if they meet the uniformity requirements for the irrigation water application.

(c.4) Sprinkler performance and selection procedures

Before a sprinkler can be selected to apply water, it is necessary to understand what a sprinkler is, how a sprinkler works, and what a sprinkler is expected to do. Sprinklers come in many shapes and sizes. Some rotate driven by momentum, a kicker or a gear box and some splash the flow of water onto and over a splash plate. Many different materials are used to build sprinklers including brass, steel, rubber, and plastic. Most sprinklers apply water to a full-circle while some have been modified to apply water to only parts of the full circle. A conventional full-circle sprinkler throws water in a circular pattern with most of the water falling near the sprinkler and less falling near the wetted radius, Figure 6.2. The increased land area being covered as the outer edge of the circle is approached causes much of this triangular distribution. Most sprinklers, especially those used most often in agricultural applications, are impact sprinklers that cover a full-circle.

Since a single sprinkler cannot apply water at a uniform rate, several sprinklers must be located so the contributions from two or more sprinklers will sum to a constant depth. This should lead us to place the sprinklers a wetted radius apart so the addition of the two adjacent triangular distributions will yield a uniform depth. The placement of sprinklers is further complicated by the effect of the sprinkler's operating pressure and wind speed.

(c.4.a) Operating Pressure

The distribution pattern shown in Figure 6.2 is expected from all sprinklers operating at an "acceptable" design pressure as "recommended" by the sprinkler manufacturer. This is sometimes referred to as the "proper" pressure or "proper pressure range". Manufacturers of sprinklers present the expected performance of their sprinklers in performance charts. Several typical sprinkler performance charts are shown in Appendix C. These charts, one for each sprinkler, tells the buyer, user, or designer what flow rate, in gallons per minute (gpm), and wetted diameter, in feet, the sprinkler will produce at each of several pressures. Each model is available with several different nozzles or 'nozzle sets'. Technically each different nozzle or nozzle set constitutes a different sprinkler with a different performance, see Appendix C. On some sprinkler performance charts there are shaded areas representing portions of the pressure range (shown on the left-hand side) that are either too high or too low. Many of the sprinkler performance charts given in Appendix C have low- or high- pressure ranges. These low or high-pressure shaded areas represent performance data provided by the manufacturer, but these sprinklers should not be operated at these 'low' or 'high' pressures. The effect of 'low' and 'high' pressure on the distribution of water coming from a sprinkler is shown in Figure 6.3. The water discharging from the nozzles at unusually 'high' or 'low' pressures causes these perturbed distributions. These unacceptable pressures cause the droplets of water leaving the nozzles to be either too large (low pressure) or too small (high pressure) to provide the proper distribution of water.

Figure 6.2 Typical Sprinkler Distributions When Pressure within Manufacturers Recommended Range

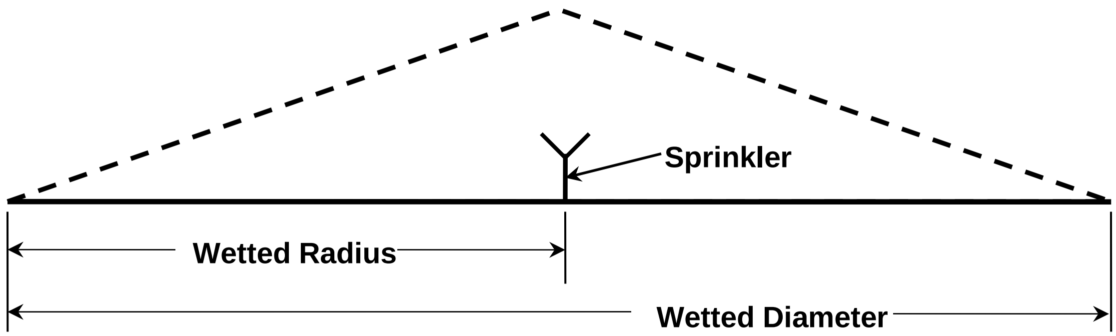
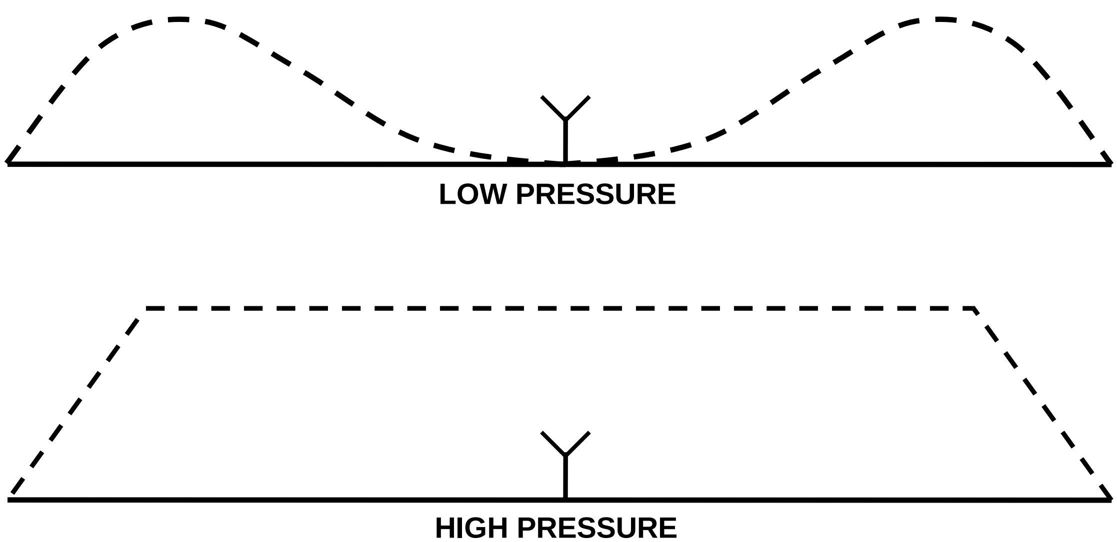
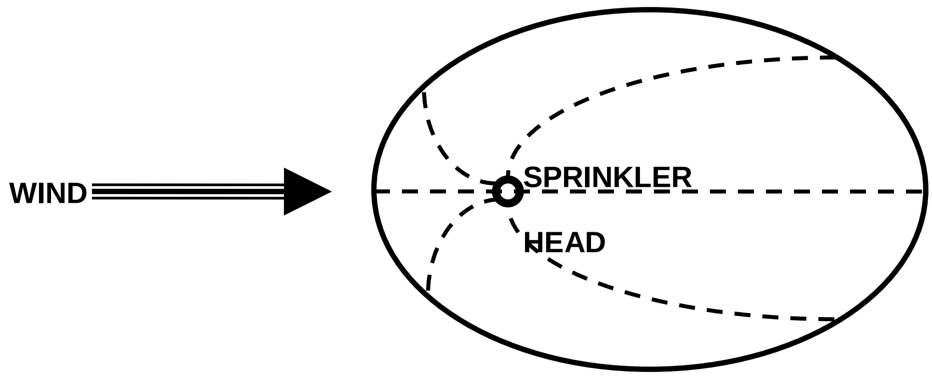


Figure 6.3 Sprinkler Distributions when Pressure is Too High or Too Low.



(c.4.b) Wind
Droplets discharging from a sprinkler are affected by the wind if wind is present. The effect of wind is shown in Figure 6.4 where it can be seen how the droplets tend to be blown down wind to form an egg-shaped distribution rather than a circle. The effect of wind cannot easily be compensated for especially if wind direction changes during the operating period. The effect of wind is, therefore, compensated by moving the sprinklers closer together than would be indicated by the previous discussion.

Figure 6.4 Effect of Wind on a Sprinkler's Distribution



(c.4.c) Sprinkler Wetted Diameter

From Figure 6.2, it can be implied that it would be best to place the sprinklers a radius apart or what is known as 'head-to-head' spacing or sometimes referred to as a 50% spacing. The term %Spacing, (%S) is defined as

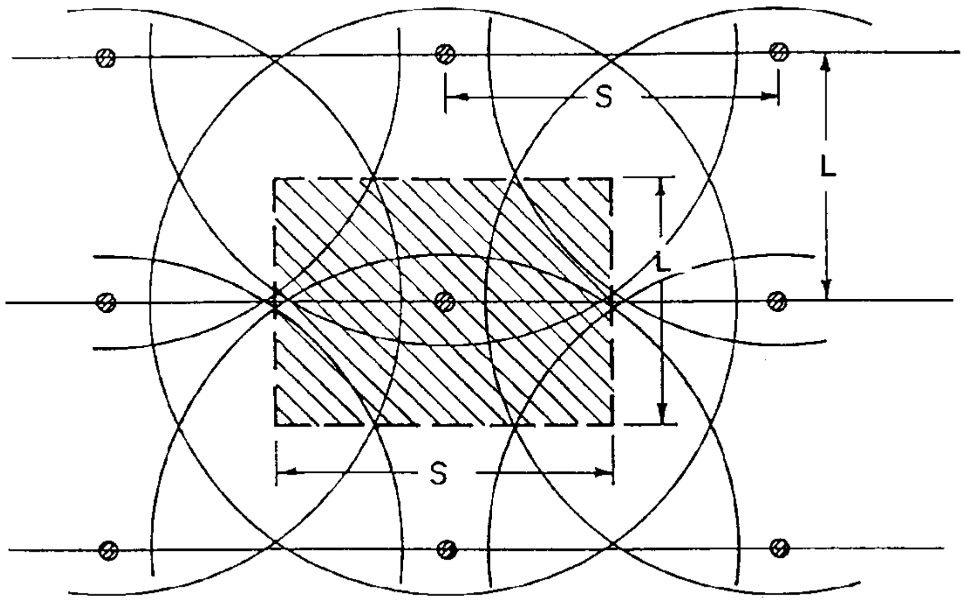
$$\%S = \frac{S}{WD} \tag{6.7}$$

where S is the distance or spacing between sprinklers in feet, and WD is defined as the wetted diameter of the sprinkler in feet, see Figure 6.2. As wind speed increases the %Spacings are usually adjusted as shown in Table 6.1. Notice that at low wind speeds it is not uncommon to extend the spacing beyond the head-to-head coverage (50% Spacing) criteria. This can be done because the top of the triangular, ideal sprinkler distribution, Figure 6.2 is often slightly flattened yielding a zone near the sprinkler with nearly uniform application. The existence of this nearly uniform area near each sprinkler permits the %Spacing to increase slightly and still maintain excellent coverage. Almost all sprinklers systems are designed for an 8-mph wind, thus the 50%S (or head-to-head coverage) is the most common and most desirable sprinkler overlap found in sprinkler systems. A general rule of thumb for Pennsylvania is to use the 50%S and adjust as needed to meet the NRCS 442 CPS for Sprinkler Irrigation.

Table 6.1 Most desirable percent spacings as a function of wind speed

Wind Speed (mph)	Desired % Spacing (%S)
0	65
0 to 5	60
5 to 8	50
> 8	20 to 30

Figure 6.5 Theoretical Area of Coverage for a Sprinkler.



(c.4.d) Sprinkler Selection

Sprinkler selection is the process by which the designer selects the best sprinkler from the list of available sprinklers; either one of those in Appendix C or a sprinkler available from a manufacturer. Prior to the sprinkler selection process, the design application rate and the spacing between the laterals, L and the spacing between the sprinklers on each lateral, S must be known. These topics have already been discussed above. From these three parameters, it is necessary to compute, or identify three specific parameters needed as the sprinkler selection process is initiated. These parameters are (a) the sprinkler's required flow rate, (b) the sprinkler's proper pressure range, and (c) the desired wetted diameter of the sprinkler.

(c.4.d.1) Sprinkler's Required Flow Rate

The sprinkler's required flow rate is based on the theoretical area that is the responsibility of each sprinkler. Because of the overlapping between adjacent sprinklers, it is necessary to look at the larger system of sprinklers, all spaced according to the selected S x L, Figure 6.5. When the larger field of sprinklers is examined it becomes obvious that each sprinkler is responsible for the land area that is equal to the square or rectangle with a sprinkler in each corner.

Thus, the theoretical area that each sprinkler is responsible for is the spacing, S x L, see Figure 6.5. The volume of water thrown out of the hatched area by the sprinkler at its center is equal to the volume of water thrown into the hatched area by the adjacent sprinklers. Therefore, the rate at which water must be applied to this theoretical area of coverage by each sprinkler, so that the area receives water at the desired application rate A_r, must be at a discharge rate equal to:

$$Q = \frac{(S \times L)A_r}{96.3} \tag{6.8}$$

where S and L are the sprinkler spacings, in feet defined above, A_r is the design application rate in inches per hour (in/hr), 96.3 is a constant that converts ft^2-in/hr to the sprinkler flow rate Q in gpm. This sprinkler flow rate is the first and most important sprinkler selection criterion. If for any reason a sprinkler cannot be found that has this computed discharge, the application rate will not be equal to the design or prescribed application rate selected in Section c.2. The sprinkler discharge of the selected sprinkler must be as close as possible to the results computed by Equation 6.8.

(c.4.d.2) Sprinkler's Proper Pressure Range
The second criterion is to select a sprinkler that yields the required discharge, Equation 6.8, while operating at a pressure within the manufacturer's proper pressure range. The sprinkler performance charts, reproduced in Appendix C, each provide some range of pressures that are recommended by the manufacturer. In some cases, these minimum and maximum pressure limits are established by the limits of the chart. In other cases, there is a shaded region near the top (low pressure) or bottom (high pressure) to indicate unacceptable pressures for that sprinkler. If a sprinkler cannot be found with a discharge within a sprinkler's 'proper' pressure range, the uniformity of water distribution will be poor, see Figure 6.3.

(c.4.d.3) Sprinkler's Wetted Diameter
In addition to determining the required sprinkler discharge and proper pressure, it is important to select a sprinkler that has a wetted diameter that will create the necessary overlap. Since nearly all sprinkler systems are designed for a 50%S, it is important that the sprinkler selected have a wetted diameter nearly equal to two times the smaller of S and L, or from Equation 6.7, the desired wetted diameter, WD should be:

$$WD = \frac{(S\ or\ L)_{min}}{\%\,S} = \frac{(S\ or\ L)_{min}}{0.5} \qquad (6.9)$$

where $(S \text{ or } L)_{min}$ is the smaller of the sprinkler spacing, S and L in feet. At high application rates (> 0.50 in/hr) this criterion can usually be met. In other words, a sprinkler is usually available that will have a discharge specified by Equation 6.8 and a wetted diameter specified by Equation 6.9. In most irrigation designs, however, the application rates chosen are usually lower than 0.50 in/hr. From Table 2.1 it can be seen that for many natural soils, the maximum intake rate is at or below 0.50 in/hr. Therefore, an application rate that is as low as reasonable, often in the range of 0.20 to 0.50 in/hr. is chosen. When selecting sprinklers to satisfy these lower application rates, it will be discovered that the 50% spacing criterion is often difficult to attain. Stated another way, those sprinklers that have the required discharge, will have a wetted diameter smaller than the value specified in Equation 6.9. Since a sprinkler must be selected from those available, the question arises, "How much may the 50%S criterion be stretched?" The answer is not easy. If the crop to be irrigated is very sensitive to variations in water applied, it may be necessary to go back to the application rate selection procedure and re-select a higher application rate. On the other hand, most crops are not this sensitive. As will be seen later (when the laterals are designed) most crops cannot distinguish between depths of water applied that differ by as much as 10%. If one corn plant gets 1.0 inch of water and a second corn plant gets 0.90 inches of water (a 10% difference) the two corn plants will have the same yield. Therefore, it is generally acceptable to select a sprinkler that will yield at least a 65%S.

Thus far the most important criterion when selecting a sprinkler is the sprinkler flow rate computed from Equation 6.8. The second most important criterion is to select a sprinkler that operates within the manufacturer's 'proper' pressure range. The third most important criterion is to select a sprinkler with a wetted diameter as close to that given by Equation 6.9 (50%S) even though under many conditions, a sprinkler with a slightly smaller wetted diameter (65%S) is acceptable. Also note that sprinklers with larger wetted diameters are actually better. In other words, a sprinkler system with a 40 or 45%S is, in fact, better than one with a 50%S. In general, a sprinkler that (a) has the required flow rate, (b) proper pressure, and (c) has the largest wetted diameter is the best choice. If the largest available wetted diameter is smaller than that needed for a 65%S, it may be necessary to re-select the application rate or the sprinkler spacing.

Now the question arises, "Are there other criterion that should be considered, especially in cases where the first three criteria have been adequately satisfied?" The answer is yes. These include the desire to select a sprinkler with a low operating pressure. If two equally good sprinklers exist, the one with the lower pressure will be less costly to operate. Another lesser important issue is whether the sprinkler has multiple nozzles or a single nozzle. Multiple nozzle sprinklers usually produce a better distribution of water.

(c.4.d.4) Sprinkler Selection Summary

The sprinkler selection criteria, in order of importance are:

1. The sprinkler must have the required discharge as given in Equation 6.8.
2. The sprinkler must operate within the proper pressure range as presented by the manufacturer.
3. The sprinkler should have a wetted diameter that establishes a 50% spacing.
4. The sprinkler should have the lowest available operating pressure.
5. The sprinkler should have more than one nozzle, if available.

Example 6.4 Select the best available sprinkler (from Appendix C) for the example potato irrigation system shown in Figure 6.1. From earlier analyses, the sprinkler system will have a 40- by 30-foot spacing and the system is to apply water at an application rate of 0.27 inches/hour. Select the best sprinkler from those presented in Appendix C.

Solution: Use Equation 6.8 to determine the required sprinkler discharge:

$$Q = \frac{(S \times L)A_r}{96.3} = \frac{(40)(30)(0.27)}{96.3} = 3.4 gpm$$

Using Equation 6.9 and 30 feet and 65% minimum gives an acceptable wetted diameter of 46 feet and using the 50% the 40 feet would yield a much better wetted diameter of 80 feet.

Go to the sprinklers listed in Appendix C and look for possible sprinklers that might serve this purpose:

Sprinkler	Nozzles (in)	Pressure (psi)	Q (gpm)	WD (ft)
B1	1/8	50	3.4	80
B2	9/64	33	3.4	76
C1	9/64	35	3.4	82
C2	5/32	26	3.4	82

The four sprinklers in the table above are the only sprinklers that satisfy the requirements of this system. All have a flow rate of 3.4 gpm. All operate within the manufacturer's proper pressure range. All have wetted diameters greater than 46 feet, and all meet the desired 60-foot wetted diameter. In this case, it comes down to operating pressure and whether there is something better with a single or double nozzle sprinkler. Sprinkler C2 needs the lowest pressure and might be the best choice from a pressure standpoint. All are single nozzle sprinklers. In this case, any of the four available sprinklers would do a good job. Because of the larger wetted diameter of "C1 and C2", and "C2" operates at 26 psi, the best sprinkler is "C2".

(c.5) System Pipe Layout

(c.5.a) General

After a management scheme has been chosen, the lateral spacing and sprinkler spacing selected, and the sprinkler chosen to apply the water uniformly at the design application rate, the supply piping network must be located and sized. An irrigation system consists of three types of piping. The pipe that carries water from the water supply to the pump is known as the **suction** line. Depending on the type of water supply and the pump's location, an irrigation system may or may not need or have a suction line. Pumps located in wells do not have suction lines. Pumps located on the bank of a stream or pond will need suctions lines. The pipe that carries the water from a single supply point, usually near the edge of a field to a series of equally-spaced sprinklers, all of which operate at the same time, is called a **lateral**. A lateral has one inlet and many, equally spaced outlets (sprinklers) and is, therefore, a complex hydraulic system that requires care and knowledge of fluid mechanics to design. Manifolds and submains should also be designed as laterals. The pipe that carries water from the pump to the lateral(s) is called a **main** or a main transmission line. Generally, a main has one inlet and one outlet.

(c.5.b) Suction Pipe

For reasons that will become evident later, the pump should be located as close to the water supply as is practical. The goal is to keep the suction line as short (10 to 20 feet) as practical. In some systems where start-up and shutdown is automated, the pump is located below the water surface and no suction line is needed. Suction lines are sized to minimize the friction in the pipe. Therefore, suctions lines should be "short" and "large".

(c.5.c) Lateral Pipe

After the management decisions have been made and the sprinklers selected, the laterals are probably the most important part of the irrigation system. The laterals carry water from the main to each individual sprinkler spaced uniformly along the lateral. To produce uniformity of distribution in the field, each sprinkler is expected to discharge the same amount of water. This requires that the pressure driving the water through each sprinkler on a lateral should be the same. Generally, the lateral is selected to be one size throughout and should be located in the field so the water in the lateral flows downhill (preferred) or on the contour. If laterals must be placed so water flows uphill, the elevation gain along the lateral should be minimized. Laterals are sized to provide uniformity of coverage within the limits of the crop to detect the non-uniformity.

(c.5.d) Main Pipe

Mains are the pipes that connect the pump to the lateral, laterals, or manifold. Mains are usually placed along field boundaries, or in some cases will be placed through the center of a field to shorten the laterals on either side of the main. Mains should have only one outlet. Mains are sized to minimize the cost of the irrigation system.

(c.6) Fluid Mechanics of Pipe Flow

(c.6.a) Bernoulli's Equation

Bernoulli's Equation is the basic relationship used to evaluate pressures and pump requirements within an irrigation system. To evaluate the energy state, and therefore the pressure, at any location in a pipe system it is necessary to relate the various energy forms in a piping system. Bernoulli stated that the total energy at any point in a piping system must equal the total energy at any other point in the same pipe system with two exceptions. The first exception is that energy can be lost due to friction as the water flows through the pipe between the two points in question. The second exception is that a pump is the only way energy can be added to the energy in a piping system. From Figure 6.6, the total energy, TE_A at Point A is:

$$TE_A = Z_A + 2.31 p_A + \frac{V_A^{\ 2}}{2g} \qquad (6.10)$$

where each term has units of feet. Similarly, the total energy at Point B is:

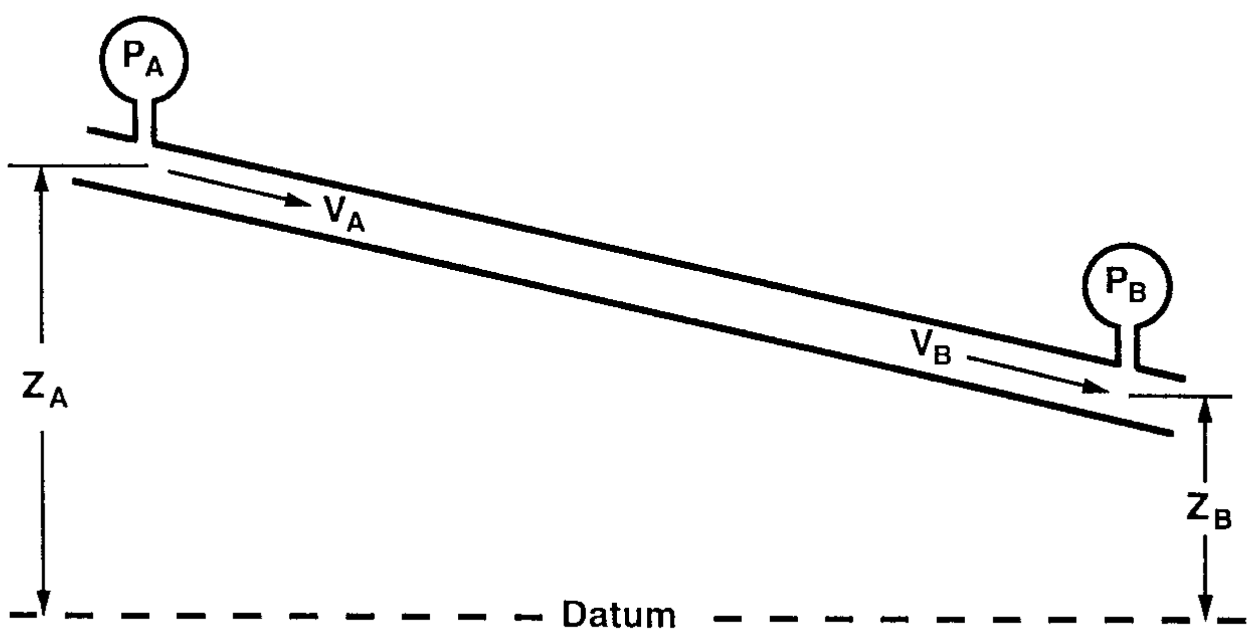
$$TE_B = Z_B + 2.31p_B + \frac{V_B^{\ 2}}{2g} \quad (6.11)$$

Since Bernoulli stated that $TE_A = TE_B$ except for losses due to friction (H_L) or energy input due to a pump (H_T), the total Bernoulli Equation used to evaluate pipe flow can be written as:

$$Z_A + 2.31p_A + \frac{V_A^2}{2g} + H_T = Z_B + 2.31p_B + \frac{V_B^2}{2g} + H_{L_{AtoB}} \quad (6.12)$$

This equation describes the total energy state within a piping system. Each term has units of feet, and is thus sometimes referred to as a 'head' or 'depth of water' instead of a pressure. Please note that for Equation 6.12 to work properly, the water MUST flow from Point A to Point B; from the point on the left-hand side of the equation to the point on the right-hand side of the equation. Bernoulli's Equation will be further developed and simplified after the pipe sizing section. But first more detail is needed about several of the terms and concepts used within Bernoulli's Equation.

Figure 6.6 General Piping System



(c.6.a.1) Elevation
Water exerts a force by virtue of the depth of water above a point. This is the same force experienced by divers and is a form of potential energy that can either be expressed as feet of depth ('head') or as pressure in pounds per square inch (psi). The following conversion shows the relationship between depth of water (or head) and pressure:

$$\frac{1.0 lbs}{in^2} \times \frac{ft^3}{62.4 lbs_{H_2O}} \times \frac{144 in^2}{ft^2} = 2.31\, ft\,/\,psi \quad \text{or } 0.43 \text{ psi/ft} \qquad (6.13)$$

This conversion is quite easily applied. For example, if a water tower is 70 ft high, the pressure at the base of the water tower will be 70 ft/2.31 ft/psi = 30 psi. This relationship is the connection between elevation and pressure. Any pressure can be converted to an equivalent height of water (or head) and any height of water can be converted to an equivalent pressure.

(c.6.a.2) Pressure
Water flowing in a pipe is moved from one location to another by the pressure difference existing between the two points. In an irrigation system it is necessary to deliver water to each sprinkler at the sprinkler's design operating pressure. This energy must be imparted to the water either by a pump or by an elevation difference. Pressures are usually expressed as psi but can easily be converted to a head using the 2.31 ft/psi conversion, Equation 6.13.

(c.6.a.3) Velocity
The kinetic energy of water flowing in a pipe is related to the velocity of flow as $V^2/2g$ where V is the velocity in feet per second (fps) and g is the acceleration of gravity as 32.2 ft/sec^2. The velocity of water flowing in a pipe can be obtained from the pipe friction charts presented in Appendix B. Each pipe size presented for each type of pipe has two columns. The column on the left is the flow velocity. For example, the velocity of flow in a 2-inch diameter PVC-160 pipe carrying 70 gpm is 5.93 fps.

(c.6.a.4) Friction
Water moving through a pipe loses energy or is retarded by friction as the water rubs against the inside of the pipe. Friction exerted on the water by the pipe walls is energy lost from the system. Friction energy is heat and cannot be recovered. Friction or head loss, H_L is a function of the flow rate in the pipe, the type of pipe (especially its roughness), the diameter of the pipe, and the length of the pipe. Engineers have formulated several methods of computing friction in pipes. The most commonly used method is the Hazen-Williams Equation that relates friction or head loss as:

$$V = 1.318 C R^{0.63} S^{0.54} \qquad (6.14)$$

where V is the flow velocity in fps defined as Q/A from the continuity equation, R is the hydraulic radius defined as:

$$R = \frac{A}{W_p} = \frac{\frac{\pi D^2}{4}}{\pi D} = \frac{D}{4} \qquad (6.15)$$

C is the Hazen-Williams pipe friction coefficient, and S is the slope of the total energy line, which is the head loss. By substituting the continuity equation for the velocity, V, the area formula, and defining the head loss, S as H_L/L in Equation 6.14 and solving, the head loss, H_L can be defined as:

$$H_L = 4.72\left(\frac{Q}{C}\right)^{1.85}\frac{L}{D^{4.87}} \qquad (6.16)$$

where Q is the flow rate in cubic feet/sec (cfs), D is the pipe diameter in ft, L is the pipe length in ft, and C is the Hazen-Williams pipe friction coefficient. By applying Equation 6.16 to each pipe as a function of the pipe diameter and the flow rate, the values shown in Appendix B under the columns labeled 'psi loss' can be computed. These values are commonly referred as friction factors, F_c and have units of psi/100 ft. These friction factors represent the head loss in psi in each 100 feet of pipe. Friction factors are commonly published in tables similar to those in Appendix B. Depending on the company or group developing the tables the friction factors may be presented in different units. The most commonly used units are psi/100 ft, or ft/100 ft, or ft/1000 ft. Friction factors for various types of irrigation pipes are given in Appendix B. Note that the only units presented for the friction factors in Appendix B are psi/100 ft.

Friction factors are given in Appendix B for most common types of irrigation pipe. Note that as the discharge increases the friction factor as well as the velocity increases.

Friction in a specified length of pipe is determined by substituting the friction factor, F_c and the length of pipe, L in feet into the friction formula as:

$$H_L = F_c L \qquad (6.17)$$

The following example illustrates how Equation 6.17 should be used.

Example 6.5 Determine the head loss in a 900-foot length of 3-inch PVC-160 pipe carrying 110 gpm.

Solution: From the PVC-160 table in Appendix B, the friction factor for 3-inch PVC-160 pipe carrying 110 gpm is 0.86 psi/100 ft. By substituting into Equation 6.17 the head loss is:

H_L = (0.86 psi/100 ft) (900 ft) = 7.7 psi x 2.31 ft/psi = 17.8 ft

Several foundational concepts relating to water flow in pipes have been developed, thus it is possible to develop the procedures needed to size each type of irrigation pipe. It is best to begin with main lines because the process is the most straightforward. The sizing of suction lines is rather empirical and related to the main size so these will be discussed second. The most complex and most difficult pipe to size is the lateral. Lateral sizing will be saved for last even though the lateral is typically the first pipe sized in an irrigation system design.

(c.7) Pipe Types and Selection

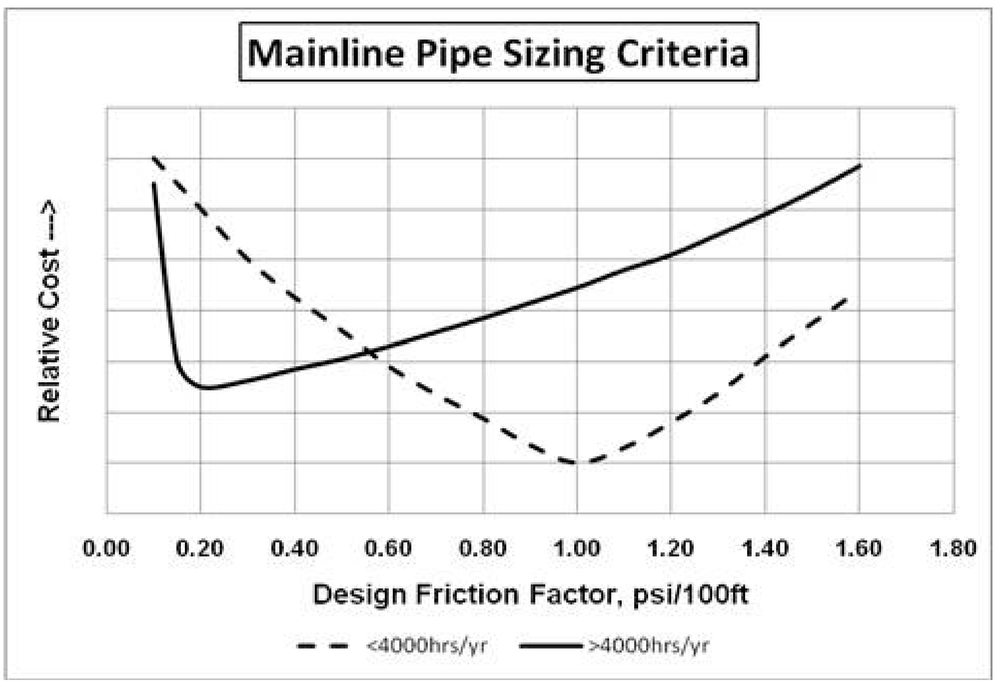
The type of pipe selected for use in an irrigation project is usually dependent on availability, cost and friction characteristics. Other factors that should also be considered are weight of the pipe, corrosion characteristics, flexibility and ease of installation. Additional information can be found in NEH part 623 Chapter 11, Sprinkler Irrigation.

(c.8) Pipe Sizing Procedures

(c.8.a) Mains
Main supply lines deliver water to only one outlet. They are sized such that the total cost of the irrigation system, including hardware and energy, is minimized. Pipes are sized by selecting pipes that have a certain level or amount of friction. By keeping the friction or head loss low the energy required to pump the water is minimized. To minimize friction, however, it is necessary to use very large pipe, which is very expensive. Therefore, there is a compromise needed between the cost of the pipe and the cost of the energy required to operate the pump.

To minimize the total irrigation system cost, mains are sized by choosing the pipe that will cause the friction in the pipeline to be approximately equal to 1.0 psi/100 ft of pipe, see Figure 6.7 (minimum cost). This criterion will generally yield the most economical system for main transmission pipelines that carry water less than one-half of the time; <4,000 hr/yr. For mains that are used more than half time, >4,000 hr/yr, the friction in the pipeline should be approximately 0.2 psi/100 ft (minimum cost). If a pipe size cannot be found with the exact (minimum-cost friction factor) as shown in Figure 6.7, it is usually best to choose a pipe with a friction factor that is slightly larger than the design friction factor instead of one slightly smaller. An additional consideration is that the velocity of flow in main transmission pipelines should never exceed 5.0 ft/sec, especially if quick closing values follow the location of high velocity. The next example will demonstrate the proper procedure for sizing mains.

Figure 6.7 How irrigation system relative cost changes with the mainline design friction factor



Example 6.6: Determine the proper size PVC-160 main to carry 50 gpm. This pipe is part of a supplemental agricultural irrigation system that carries water about 150 hr /yr

Solution: Since this pipe will be used less than 4,000 hr /yr, the design criteria of $F_c = 1.0$ psi/100 ft should be used. From the PVC-160 friction chart in Appendix B, look on the left for

50 gpm. Scan from left to right, looking at the friction factor columns. The 1.0-inch pipe has a friction factor of 25.07 psi/100 ft; this is greater than 1.0 psi/100 ft and therefore, it is too high. Continue to scan from left to right until the 1.25-inch pipe, with a friction factor of 7.49 psi/100 ft is found; this is also too high. Continue scanning the larger pipes to find the friction factors of 3.88 psi/100 ft for the 1.50-inch pipe (still too high) a friction factor of 1.31 psi/100 ft for the 2-inch pipe (still too high) and the friction factor of 0.52 psi/100 ft for the 2.5-inch pipe. Note that either the 2-inch (1.31 psi/100 ft) or the 2.5-inch (0.52 psi/100 ft) would be appropriate choices. Since the 2-inch pipe shows (Figure 6.7) a lower relative cost than the 2.5-inch pipe the 2-inch PVC-160 pipe is the best choice to carry 50 gpm. Note also that the velocity in this pipe is less than 5.0 fps.

(c.8.b) Suction Lines

Suction lines should be sized to produce very small friction loss. The goal when sizing a suction line is to minimize the friction, or head loss in the suction line. To properly size a suction line, take the discharge flowing through the suction line and size it as if it were a main (use which ever design friction factor is appropriate for the situation based on whether the suction line is used more or less than 4,000 hr/yr). Then make the suction line 1.0 inch larger than the size required for the main. The combination of the short length of suction pipe and larger pipe diameter will ensure that the friction in the suction line is essentially zero.

(c.8.c) Laterals

Laterals are sized such than the volume of water discharged from each sprinkler on the lateral will be within 10 percent of the volume discharged from the lateral's average sprinkler. This 10 percent difference in volume of discharge is equivalent to a 20 percent difference in pressure along the length of the lateral. Therefore, the design criteria for laterals is usually stated as:

$$\frac{P_m - P_e}{P_m} < 20\% \tag{6.18}$$

where P_m is the pressure at the main or inlet end of the lateral and P_e is the pressure at the end of the lateral away from the main (at the lateral's last sprinkler). The application of the criterion in Equation 6.18 requires that Bernoulli's Equation, Equation 6.12, be applied to the lateral taking both the friction losses and the elevation changes along the length of the lateral into account. This is a complex, difficult trial and error analysis. If, however, Bernoulli's Equation is applied in this complex analysis under the constraint of keeping the pressure difference between the entrance end and terminal end of the lateral within 20% an explicit equation can be developed with the limiting (or maximum or design) friction factor as the unknown. This maximum permissible friction factor, F_{cd} is then applied using the appropriate friction charts in Appendix B. The equation derived to determine the maximum permissible friction factor in a lateral, F_{cd} is:

$$F_{cd} = \frac{23.5P + 45.5\Delta Z + 63}{LC_f} \tag{6.19}$$

where P is the sprinkler's design operating pressure in psi (determined when the sprinkler was selected), L is the length of the lateral in feet, C_f is a correction factor taken from Table 6.2 and is a function of the number of outlets or sprinklers on the lateral, and $\Delta Z = Z_m - Z_e$, which is the elevation difference between where the main connects to the lateral and the terminal sprinkler is attached to the lateral. ΔZ is positive (+) if the lateral runs downhill from the main and negative (-) if it goes uphill. F_{cd} is the design or maximum permissible friction factor with units of psi/100 ft. The F_{cd} value is applied by using the friction chart for the pipe being used and the total discharge of water flowing (Q/sprinkler x No. of sprinklers) into the lateral. This friction factor is used with the total discharge to select the smallest pipe that has a friction factor smaller than F_{cd}. By sizing the lateral in this way, the maximum pressure difference between the two end sprinklers on the lateral will be less than 20%. This sizing procedure and Equation 6.19 assume the entire lateral will be made up of one-sized pipe.

Table 6.2 Correction Factor C_f for Friction Loss in Laterals

Number of Sprinklers	C_f
1	1.000
2	0.634
3	0.528
4	0.480
5	0.451
6	0.433
7	0.419
8	0.410
9	0.402
10	0.396
15	0.376
20	0.370
30	0.362
100	0.350
∞	0.345

Since the flow rate in each section of a lateral is different, the lateral pipe could be downsized as the flow rate decreases. However, the cost of pipe reducers is usually greater than the cost of using one-sized pipe throughout. This design procedure will be illustrated in Example 6.7.

Two final notes are offered for consideration:

1. When this lateral sizing procedure is applied, the designer may notice that the velocity of flow in the first sections of the properly sized lateral is greater than 5.0 fps. This is expected and is okay, since there are no quick-closing valves in the laterals in an agricultural system, and these high velocities produce no detrimental water hammer impacts.
2. The comments relating to proper lateral design imply that the water flow in each lateral should be from the supply main downhill to each of the sprinklers on the lateral. When laterals carry water downhill there is an opportunity to balance the energy loss due to pipe friction against the energy gain from the water flowing downhill. Since the goal in all lateral designs should be to have each sprinkler operate at its design pressure, the downhill flow geometry takes advantage of balancing the friction energy losses against the elevation energy gains, producing an efficient design.

Example 6.7 Determine the correct size PVC-160 pipe that should be used as a lateral that contains eight 20-gpm sprinklers chosen to operate at 55 psi with a spacing of 70 feet between sprinklers. The first sprinkler is located 35 feet half spacing) from the main. The elevation at the main is 350 ft. and the elevation at the last sprinkler is 340 ft.

Solution:

1. The lateral length is 8 sprinklers (70 feet) = 560 ft minus the half spacing of 35 feet = 525 feet.
2. The C_f for 8 sprinklers is 0.410, from Table 6.2.
3. $\Delta Z = Z_m - Z_e = 350\text{ ft} - 340\text{ ft} = +10\text{ ft}$.
4. Substituting into Equation 6.19 yields

$$F_{cd} = \frac{23.5(55\,psi) + 45.5(+10\,ft) + 63}{525\,ft(0.410)} = 8.41\,psi/100\,ft$$

5. The total discharge in this lateral is 8 sprinklers (20 gpm/sp.) = 160 gpm.
6. Looking to the PVC-160 chart in Appendix B, with Q = 160 gpm and the maximum friction factor = 8.41 psi/100 ft yields a minimum sized lateral of 2.5 inches. Note the velocity in the earliest sections of the lateral is greater than 5.0 fps. This is expected and is okay.

(c.8.d) Head Loss in a Lateral

If the total head loss in a lateral is desired, it can be computed using Equation 6.17 applied to each subsection (the pipe section between each sprinkler) of the lateral and summing the individual head losses. It is easier, however, to modify Equation 6.17 to include the effect of not having all of the water travel through the total length of pipe, thus yielding a working equation for head loss in a lateral as:

$$H_L = F_c L C_f \tag{6.20}$$

Equation 6.20 is demonstrated in the example 6.8.

Example 6.8: Determine the head loss in a 2.5-inch PVC-160 lateral with eight 20-gpm sprinklers spaced 70 ft apart.

Solution: For Equation 6.20, F_c = 4.45 psi/100 ft; L = 525 ft; and C_f = 0.410. Substituting into Equation 6.20 yields H_L = 9.6 psi.

(c.9) Determining Pressures and Pump Energy Requirements

It is important that designers and growers gain an understanding of how pressures vary within the various parts of an irrigation system. This discussion will also include information on how to determine the energy that must be imparted to the water entering the irrigation system, so all parts of the system will function properly. The principles that permit us to understand how pressures vary within an irrigation system are based on Bernoulli's equation developed earlier as Equation 6.12 and repeated here for convenience as:

$$Z_A + 2.31p_A + \frac{V_A^2}{2g} + H_T = Z_B + 2.31p_B + \frac{V_B^2}{2g} + H_{L_{AtoB}} \tag{6.21}$$

where Z is the elevation in feet, p is the pressure in psi, V is the velocity in fps, g is the acceleration of gravity as 32.2 ft/sec^2, H_T is the energy put into the system by the pump, in feet, and H_L is the friction or head loss between the two points in question. Equation 6.21 is the complete Bernoulli's Equation including all of the terms necessary to describe pipe flow. For practical purposes, it is possible to simplify Equation 6.21 to make it less cumbersome. In all irrigation mains, the velocity is usually limited to 5.0 fps. In many systems the velocity is considerably less than 5.0 fps. If a velocity of 5.0 fps is substituted into the velocity term in Equation 6.21, the term yields a value of only 0.39 ft or about 0.17 psi. At these, normally slow velocities, the velocity term can be neglected. Therefore, the working form of Bernoulli's equation is:

$$Z_A + 2.31 p_A + H_T = Z_B + 2.31 p_B + H_{L_{AtoB}} \qquad (6.22)$$

At this point it would be good to look back to Figure 6.6 and review that Equation 6.22 is written between two specific points in the irrigation system. As Equation 6.22 is shown, it is written between point A and point B. If properly written, the water **must** flow from point A to point B. The H_T term is the 'pump energy' term and is only used if there is a pump between points A and B. If there is no pump between the two points being examined, the H_T term is zero. The H_L term represents the total friction existing between the two points being examined. The H_L term should include both the friction expected in the pipe as well as the friction expected from valves and changes in direction and changes in pipe sizes in the section of pipe in question. There are three common methods used to account for friction expected from valves and changes in direction and changes in pipe sizes; (a) use a detailed friction chart to evaluate each special friction in the pipe section (this chart is not included in Appendix B), (b) add 10% to the length of pipe used in Equation 6.17 to cover these additional frictions, or (c) add 10% to the computed result from Equation 6.17. Any of these methods should result in friction values that correctly represent actual friction occurring in the pipe in question. If the section of pipe in question contains automatically actuated globe valves, one of these additional friction values should be employed to estimate the pipe friction.

The friction must always be included in units of feet. Equation 6.22 can be used to determine the pressure at any point in a piping system or to determine the required energy input by the pump. It can be used to solve for any unknown term as long as the other terms are known or given. In most practical applications, one of the two pressures is the unknown or the pump energy term is the unknown. When one of the two pressures is the unknown, write the equation between two points, one with the elevation and pressure known and one, with the elevation known and the pressure unknown, on the same side of the pump. When the pump energy is the unknown, the equation must be written between two points, one on the intake side and one on the output side of the pump; both the elevation and pressure must be known at both of these points. The following three examples will demonstrate the use of Equation 6.22 in determining pressures and the pump energy term.

Example 6.9: Figure 6.8 shows a suction line, pump and PVC Class 200 main to deliver 200 gpm of irrigation water to a lateral that connects to the main at point C. The pressure of 60 psi shown at Point C is the pressure needed to operate the sprinklers on the lateral; the pressure that yielded the desired sprinkler discharge and wetted diameter when the sprinkler was selected. The elevation at Point C is 550 ft. The water to supply this irrigation system is to come from the pond shown as Point S at an elevation of 580 ft. Determine the pressure required at point B so there will be 60 psi at point C.

Solution: In this example, the pressure (60 psi) and elevation (550 ft) are known at point C. The elevation (595 ft) is known at point B where the pressure is to be determined. There is no pump between points B and C, so the H_T term is zero. The water in moving from point B to C will pass through the 1,200-foot long section of 4-inch diameter PVC Class 200 main shown. This 1,200-foot length of pipe carrying 200 gpm will have a friction loss of:

$H_L = F_c L$
H_L = (0.84 psi/100 ft) (1,200 ft) = 10.08 psi = 23.3 ft of head loss.

To determine the unknown pressure at point B, first write Equation 6.22 from point B to point C as:

$$Z_B + 2.31p_B + H_T = Z_C + 2.31p_C + H_{L_{BtoC}}$$

By substituting the known information into this equation, it is:

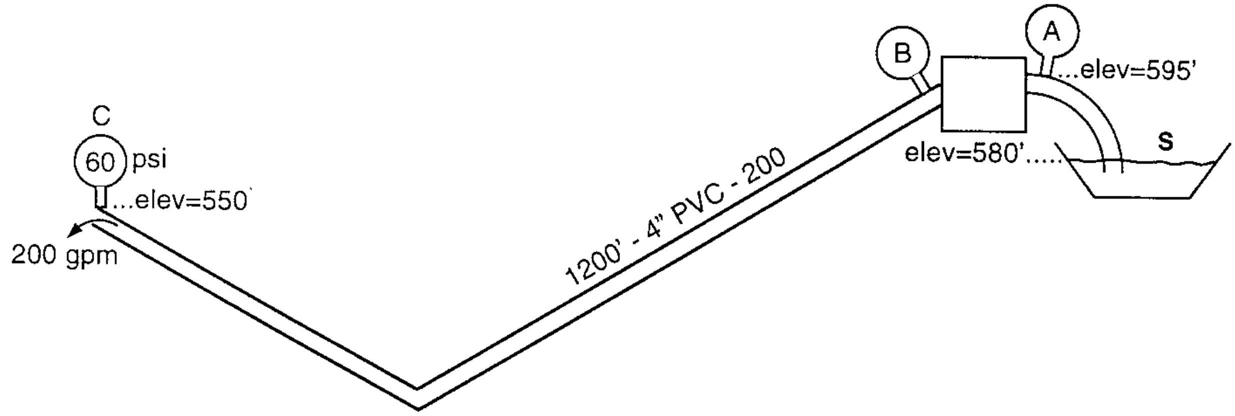
595 ft +2.31p_B + 0 = 550 ft + 2.31(60psi) + 23.3 ft

or 595 ft + 2.31p_B = 550 ft + 138.6 ft + 23.3 ft

solving for 2.31p_B = 116.9 ft

and then solving for p_B = 50.6 psi.

Figure 6.8 Pipe System for examples 6.9, 6.10 and 6.11.



Therefore, when this irrigation system is delivering 200 gpm to point C at 60 psi, the pressure gauge located just off the discharge side of the pump should read 50.6 psi.

Example 6.10: Figure 6.8 shows a suction line, pump and PVC Class 200 main to deliver 200 gpm of irrigation water to a lateral that connects to the main at point C. The pressure of 60 psi shown at Point C is the pressure needed to operate the sprinklers on the lateral; the pressure that yielded the desired sprinkler discharge and wetted diameter when the sprinkler was selected. The elevation at Point C is 550 ft. The water to supply this irrigation system is to come from the pond shown as Point S at an elevation of 580 ft. Determine the pressure at point A when the pump is discharging 200 gpm into the irrigation system.

Solution: In this example, the pressure at point A on the intake side of the pump is required where the elevation of 595 ft is known. In order to determine the pressure at point A Bernoulli's equation must be written between two points on the intake side of the pump. Note that Bernoulli's Equation should not be written across the pump unless there is no other alternative. The only other point of known elevation and pressure on the intake side of the pump is the water source, point S where the elevation (580 ft) is known and the pressure is zero psi gauge pressure. There is no pump between points S and A, so the H_T term is zero. The water in moving from points S to A will pass through the suction line which has not even been defined in this example.

The earlier discussion about suction lines noted that suction lines should be short and one pipe-size larger than the main. The reason for this criterion was to ensure that the H_L in the suction line would be approximately zero. To determine the unknown pressure at point A, first write Equation 6.22 from point S to point A as:

$$Z_S + 2.31p_S + H_T = Z_A + 2.31p_A + H_{L_{StoA}}$$

By substituting the known information into this equation, it is:

580 ft +2.31(0) + 0 = 595 ft + 2.31p_A + 0

or 580 ft + 0 = 595 ft + 2.31p_A + 0

solving for 2.31p_A = -15 ft

or p_A = -6.5 psi

Note that the pressure at point A is simply the elevation difference between the source and the pressure gauge on the suction side of the pump with a minus sign.

Example 6.11: Figure 6.8 shows a suction line, pump and PVC Class 200 main to deliver 200 gpm of irrigation water to a lateral that connects to the main at point C. The pressure of 60 psi shown at Point C is the pressure needed to operate the sprinklers on the lateral; the pressure that yielded the desired sprinkler discharge and wetted diameter when the sprinkler was selected. The elevation at Point C is 550 ft. The water to supply this irrigation system is to come from the pond shown as Point S at an elevation of 580 ft. Determine the pump energy, H_T required to operate this irrigation system in feet.

Solution: In this example, the pump energy, H_T term is required. In order to determine the pump energy, Bernoulli's Equation must be written between a point on the intake side of the pump, where the elevation and pressure are known, and a point on the discharge side of the pump, where the elevation and pressure are known. Because of the pressures determined in Examples 6.9 and 6.10, the pressures at points S and A on the intake side of the pump and points B and C on the discharge side of the pump are all known. It is possible to write Bernoulli's Equation between any combinations of these points and solve for H_T. If no mistakes were made in Examples 6.9 or 6.10, it does not make any difference, which pair of points is chosen; as long as one is on the intake and one is on the discharge side of the pump. Because of the high possibility of errors in previous computations, it is best to choose Point S on the intake side of the pump and Point C on the discharge side of the pump. This means the elevation (580 ft) and pressure (0) at Point S are known and the elevation (550 ft) and pressure (60 psi) at Point C are also known. The friction between Point S and C will be the zero (0) defined in Example 6.10 for the suction line plus the 23.3 ft defined in Example 6.9 for the 1,200-foot ling main; a total of 23.3 ft. The only remaining parameter is the unknown H_T. To determine the pump energy, H_T, first write Equation 6.22 from point S to point C as

$$Z_S + 2.31p_S + H_T = Z_C + 2.31p_C + H_{L_{StoC}}$$

By substituting the known information into this equation, it is:

$$580 \text{ ft} + 2.31(0) + H_T = 550 \text{ ft} + 2.31(60 \text{ psi}) + 23.3 \text{ ft}$$

or $$580 \text{ ft} + 0 + H_T = 550 \text{ ft} + 138.6 \text{ ft} + 23.3 \text{ ft}$$

solving for $H_T = 131.9$ ft

H_T values are usually left in units of feet.

(c.10) Pump Selection

Part 623, Irrigation of the National Engineering Handbook, Chapter 8, Irrigation Pumping Plants is an excellent source of technical material when designing pump systems and pump energy requirements for specific projects. This section will summarize several of the key elements of pump requirements needed in most practical cases.

Almost all irrigation pumps are centrifugal pumps if located above ground or turbine pumps (a minor variation of centrifugal pumps) if the pump is located in a well or below water, Figure 6.9. Both types of pumps have characteristic performance relationships similar to that shown in Figure 6.10. There is a great deal of information on a pump curve including the H_T-Q performance curves for several impeller sizes, the pump efficiency in percent, the pump horsepower, and the Net Positive Suction Head Required (NPSHR). The H_T values are shown on the y-axis, in feet and the Q values are shown on the x-axis in gpm. The NPSHR is the energy required to push water into the inlet side of the pump. The NPSHR can be used to determine the maximum elevation difference that may exist between the water level of the source and the pump intake. This elevation difference is called the maximum suction head, SH_{max} and can be expressed as:

$$SH_{max} = 33 - NPSHR \tag{6.23}$$

The 33 in Equation 6.23 is based on the elevation of 750’ above sea level. When the actual suction head, SH is less than SH_{max}, the pump will perform as designed and as described on the pump curve. If the SH is greater than SH_{max}, there will not be enough energy to push the water into the pump and the water will begin to vaporize in this partial vacuum environment within the pump housing. This vaporization is called cavitation and can seriously damage the impellers of the pump.

Figure 6.9 Cross-Sections of Turbine and Centrifugal Pumps.

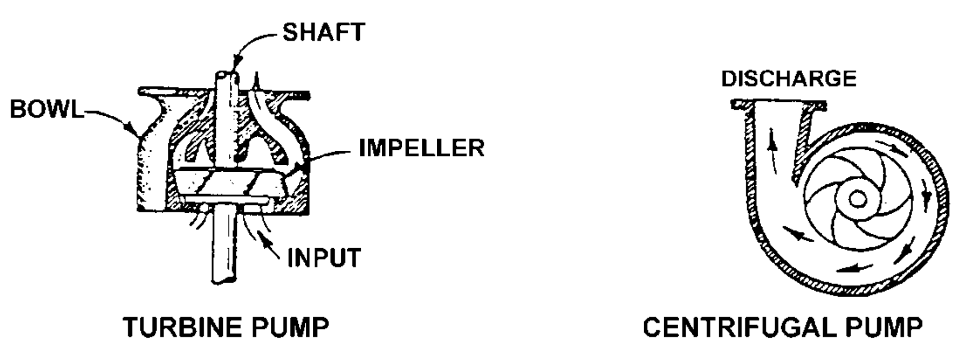
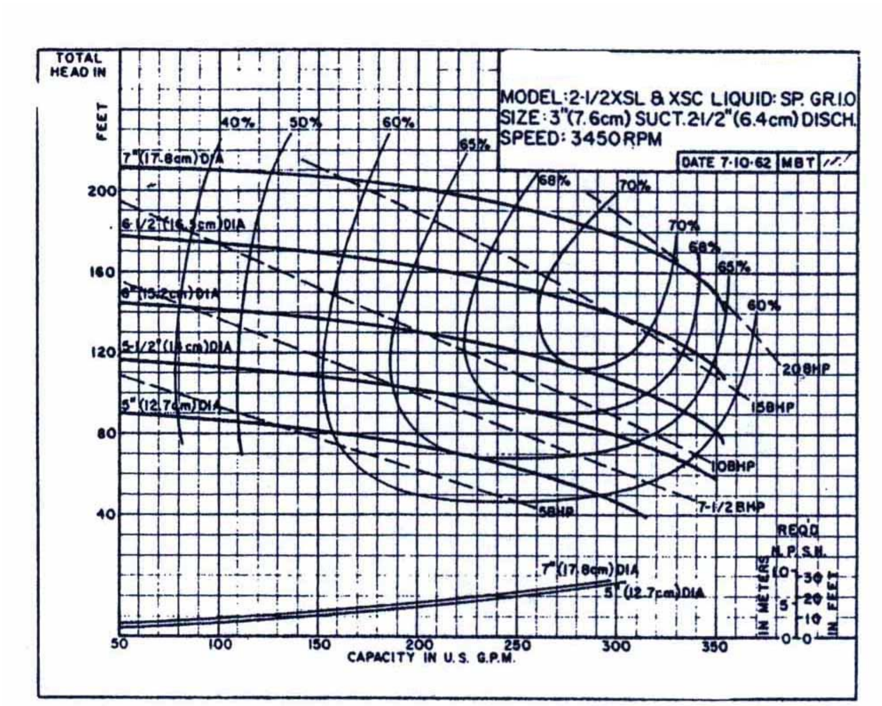


Figure 6.10 Typical Centrifugal Pump Curve.

(c.11) Power Unit Sizing



The horsepower rating, H_P of the engine or power unit required to operate a pump can be sized by understanding the energy losses expected between the water that is to receive the energy and the engine that is to impart the energy to the pump. From the total head, H_T calculated from Bernoulli's Equation and the total pump discharge, Q the power required to turn the pump shaft can be computed as:

$$H_P = \frac{H_T Q}{3960(E_t)} \qquad (6.24)$$

where E_t is the total efficiency of the pump and engine system and is the product of the pump efficiency, E_p, the connection efficiency between the motor and pump, E_c and the power unit rating efficiency, E_m, which are related as:

$$E_t = E_p \times E_c \times E_m \qquad (6.25)$$

The pump efficiency, E_p is obtained from the pump curve. The connection efficiency, E_c is usually assumed to be 100% (1.0) if the motor and pump are directly connected and 90% (0.9) if the motor is connected to the pump by gears or a belt. The power unit rating efficiency is given in Table 6.3 for several typical engines.

Table 6.3 Power Unit Rating Efficiencies

Type of Motor	E_m (%)
Electric	95
Diesel	80
Gasoline (water cooled)	70
Gasoline (air cooled)	60

(d) Stationary, and Traveling Guns, and Center Pivot Irrigation Systems

(d.1) General

There are several additional types of sprinkler irrigation systems that are widely used in Pennsylvania. These include stationary guns, traveling guns, and center pivot systems. Traveling guns and center pivot sprinkler irrigation systems are usually purchased from an irrigation distributor as a package including significant planning and design consultative services. Therefore, by the time the unit is purchased, many of the planning and design decisions about size and location of sprinkler(s) and pipe sizes have already been made. The following sections do not provide detailed design information for either of these systems. But relationships showing how to check the depth of water applied and the application rate of the system are given so the designer or operator can, if desired, check these parameters. Decisions about when and how much water to apply will be covered in Chapter 9. Some assessment tools, suggestions, and cautions will be presented to help those assisting the grower in making decisions regarding these units.

(d.2) Stationary Guns

A stationary gun is a single large sprinkler mounted onto a frame that holds the sprinkler 2 to 5 feet above the soil surface in a vertical orientation. These, so called, “big guns” are usually single-nozzle sprinklers with the single nozzle having a diameter of at least 0.50 inches. The sprinklers listed in Appendix C, Table C.I are all big guns. Note their large radii and larger flow rates. Also notice that these sprinklers are designed to operate at higher pressures than their smaller cousins (Appendix C, A to H). Thus, the first requirement for a stationary sprinkler is the need for a bigger pump and power unit, and the pipe (usually PE pipe) that supplies water to the gun will need to be larger than might be expected.

Just like the smaller sprinklers, big guns need to be spaced to provide some overlap. Manufacturers have redesigned the nozzle geometries of big gun nozzles to make it possible to reduce the sprinkler overlap somewhat and still produce a reasonably uniform depth of water applied to the area. These altered sprinkler distributions usually have a reasonably flat depth of water applied to the area from 30 or 40% of the radius to about 60 to 70% of the radius. A general rule of thumb for Pennsylvania is to use a 50% spacing but adjust as needed to meet the NRCS 442 CPS for Sprinkler Irrigation.

Most irrigators, who choose a stationary gun, usually purchase only one sprinkler. They locate the sprinkler in the middle of the area they choose to irrigate, run the sprinkler for the specified set time, then shut down the sprinkler and move it to a new location. This process is repeated until the total area needing water has been irrigated.

Many of these stationary guns are used to irrigate liquid manure and the degree of application uniformity is not quite as critical.

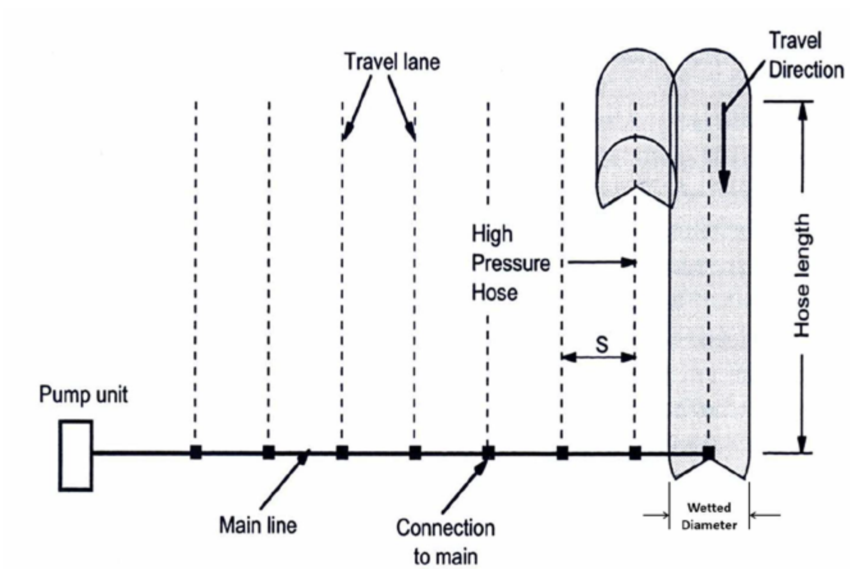
The pipeline supplying water to the big gun should be sized as a main (one outlet) with a design friction factor of about 1.0 psi/100ft.

(d.3) Traveling Guns
A traveling gun is a “big gun” sprinkler (>0.5-inch diameter nozzle) mounted on a wheeled unit that is propelled through the field at a speed set by the operator, see Figure 6.11. Water is pumped through a flexible hose to the sprinkler mounted on the traveler. The sprinkler may rotate through a full-circle or may only rotate through a portion (usually 230 to 270 degrees) of the circle. The sprinkler mounted on the wheeled rig is pulled through the field by a cable connected to a take-up reel or by the pipe being taken-up on its own take-up reel. See Figure 6.11, for an example of a reel unit anchored at the field edge.

The primary advantage of travelers is that they can apply water to a crop using a system that has fewer sprinklers to manage.

Figure. 6.11 Traveler

Figure. 6.12 Operation Layout for a Traveling Gun System. (Adapted from Pair, 1975)



There are also several disadvantages to using traveling guns to apply irrigation water. These include uneven distribution of water; as not all areas of the field will receive the same depth of water. This problem can be compensated for by overlapping the paths about 20%, see Figure 6.12. Another disadvantage of traveling guns is the large droplets that are formed as the water exits the nozzle. These large droplets hit the crop or soil surface with a great deal of energy; energy that can damage crops and/or compact the soil.

(d.3.a) Application Depth

The depth of water applied to the field during each pass of the traveler is the application depth. The application depth, D_a can be estimated by first determining the sprinkler's flow rate in gallons per minute (gpm), the speed the traveler moves through the field S_d in ft/min, and the wetted diameter of the sprinkler, W_d in feet. From these parameters, the depth of water applied during each pass through the field can be determined as

$$D_a = \frac{1.6Q}{W_d S_p} \qquad (6.26)$$

Where D_a = application depth (inches)
Q = sprinkler flow rate (gpm)
W_d = sprinkler wetted diameter (feet)
S_p = traveler speed (ft/min)
1.6 = constant unit conversion factor

Equation 6.26 was developed under the assumption that the distance between the traveler paths in the field was equal to the sprinkler's wetted diameter, W_d. Many traveler systems are designed and managed using this assumption to minimize the number of passes required to cover (or irrigate) a field. Because sprinklers do not apply water uniformly and wind distorts even the best sprinkler distribution, sprinklers are usually spaced so they are some percentage of the sprinkler's wetted diameter apart. Table 6.4 shows the percent spacings recommended for large sprinklers as a function of wind speed. Traveler paths are generally not more than 80% of the wetted diameter apart. This means that a traveler with a wetted diameter of 190 feet (W_d = 190 feet) would be used in towpaths spaced more than 0.8(190) = 152 feet apart and this assumes there is no wind.

Table 6.4 Desirable Traveler Spacings as a Percentage of the Sprinkler's Wetted Diameter. (Adapted from Pair, 1975)

Wind Speed (mph)	Percent of Wetted Diameter
No Wind	80
Up to 5	70 to75
Up to 10	60 to 65
>10	50 to 55

Great efforts have been made by the big gun manufacturers to create sprinkler nozzles that have the ability to produce a nearly uniform distribution at relatively low pressures. When sprinklers with these nozzles are used on travelers with lane spacings of about 70 to 80 percent of the sprinkler's wetted diameter, the most uniform application of water occurs.

When the influence of the wind (and related towpath spacing) are added to Equation 6.26, the sprinkler wetted diameter, W_d is replaced with the spacing between the towpaths S, which is usually from 70-80% of the sprinkler's wetted diameter. Thus, the total depth of water applied per irrigation event (or pass) is:

$$D_a = \frac{1.6Q}{(S)(S_p)} \qquad (6.27)$$

An example will demonstrate the use of Equation 6.27

Example 6.12. A traveler is to be used to irrigate a field of potatoes. The soil in this field is a silt loam. The sprinkler on the traveler has a flow rate of 200 gpm and throws water 95 feet (so the two radii equal a wetted diameter, W_d of 190 feet). The sprinkler is set to travel through the field at a speed of 3 ft/min and rotates through 230 degrees of arc. This means the sprinkler will traverse a 1,380-foot long field in 460 min (7.7 hr). Determine the depth of water applied in one pass assuming the sprinkler paths are 150 feet apart.

Solution: To use Equation 6.27, the sprinkler's flow rate, Q = 200 gpm, the towpath spacing, S = 150 feet, and the traveler speed, S_p = 3 ft/min. By substituting these values into Equation 6.27 the average depth of water applied to any point in this field can be computed as

$$D_a = \frac{1.6(200\,gpm)}{150\,ft(3\,ft/\min)} = 0.71 \text{ inches}$$

Thus, one pass of this traveler will apply an average depth of 0.71 inches of water. It should be noted that the uniformity of this depth may vary greatly depending on the sprinkler's operating pressure and wind.

(d.3.b) Application Rate

The application rate is the rate at which water is applied to any given point in the field. This rate must match or be less than the soils intake rate (the soil absorbs all the water) so that none of the water runs off the field. In a field where a traveler is used to apply water it is possible to estimate the application rate, A_r for a traveler based on the sprinkler's flow rate, Q in gpm, the sprinkler's wetted radius, R in feet, and the portion of the circle, φ in degrees receiving water as:

$$A_r = \frac{(96.3)Q\,(360)}{\pi\,(0.9R)^2\,\varphi} = \frac{13624Q}{R^2\varphi} \qquad 6.28$$

where A_r = application rate (in/hr.)
Q = sprinkler discharge (gpm)
π = the constant 3.14
R = the sprinkler's radius, which is equal to $W_d/2$ in feet
φ = portion of circle receiving water in degrees
96.3 = unit conversion factor
360 = the number of degrees in a circle
13624 = unit conversion factor

Example 6.13: Determine the application rate for the field application of water described in Example 6.12.

Solution: The application rate is determined by applying Equation 6.28 using the parameters given in Example 6.12. Thus, the application rate can be computed as

$$A_r = \frac{13642\ (200)}{95^2(230)} = 1.31\ \text{in/hr}$$

Before proceeding with the design, it is very important that the application rate be determined and that it not exceeds the soil's ability to absorb water, see Table 2.1. Note that the result of this example yields an application rate that is greater than the maximum soil intake rate given in Table 2.1 for any Pennsylvania soil. The application rate could be reduced by increasing the speed the traveler moves through the field or by selecting a smaller nozzle size which would reduce the flow rate.

(d.4) Pulsing Travelers

In recent years, pulsing travelers have been introduced and are becoming more popular with irrigators. The pulsing traveler is different from the traditional traveler in two ways; (1) The pump delivering water to the traveler in the field is smaller, and (2) the flexible hose carrying the water to the traveler can, therefore, be smaller diameter. Instead of the water being delivered directly to the sprinkler, the water is pumped into a storage chamber. When the storage chamber has been fully charged (filled and pressurized), a valve opens, and the water stored in the chamber flows through a pipe to the sprinkler nozzle and is applied to the field. It only takes a few seconds to empty the storage chamber, thus producing the pulsed application of water to the field. When the chamber has been emptied, the traveler moves forward a small distance and the cycle is repeated. Depending on the speed the pulsing traveler is set to move through the field, the end result is that pulsing travelers generally take much longer to apply a fixed volume of water than traditional travelers, and they usually apply water at a lower application rate than traditional travelers. The following example will illustrate:

Example 6.14: A pulsing traveler is to be used to irrigate a field of potatoes. The soil in this field is a silt loam. The sprinkler on the traveler has a flow rate of 100 gpm and throws water 95 feet (so the two radii equal a wetted diameter, W_d of 190 feet). The sprinkler is set to travel through the field at a speed of 3 ft/min and rotates through 230 degrees of arc. This means the sprinkler will traverse a 1,380-foot long field in 460 min (7.7 hr). Determine the depth of water applied and the application rate for the one pass assuming the sprinkler paths are 150 feet apart.

Solution: Application Depth −Substitute the sprinkler's flow rate, Q = 100 gpm, the towpath spacing, S = 150 feet, and the traveler speed, S_p = 3 ft/min into Equation 6.27 as:

$$D_a = \frac{1.6(100 gpm)}{150\, ft(3\, ft/\min)} = 0.35 \text{ inches}$$

Thus, one pass of this pulsing traveler will apply an average depth of 0.35 inches of water. As with the traditional traveler, the uniformity of this depth may vary greatly depending on the sprinkler's operating pressure. It should also be noted that the speed of the traveler, as well as the pump rate dictate the application depth. Note that the speed in this example was the same as in Example 6.12 (3 ft/min). If the traveler speed in this example is reduced to 1 ft/min, the application depth increases to 1.00 inch per pass. If the traveler speed is increased to 5 ft/min, the application depth decreases to 0.20 inches per pass.

Solution: Application Rate −As with the traditional traveler, the application rate can be computed using Equation 6.28 as:

$$A_r = \frac{13624(100)}{95^2(230)} = 0.66 \text{ in/hr}$$

Note that the result of this example yields an application rate that is greater than many of the maximum soil intake rates given in Table 2.1 for Pennsylvania soils. The application rate could be reduced by reducing the flow rate or increasing the wetted diameter.

(d.5) Center Pivot Systems

Center pivot systems consist of a single lateral supported by towers with one end anchored to a fixed pivot structure and the other end continuously moving around the pivot point while applying water, see Figure 6.13. This system irrigates a circular field unless end guns and swing lines are cycled on in corner areas to irrigate more of fields with corners. The water is supplied from the source to the lateral through the pivot. The lateral pipe with sprinklers is supported on drive units. The drive units are, normally powered by hydraulic water or electric motors. 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 larger discharge, part-circle gun is generally used at the extreme end (end gun) of the lateral to irrigate the area beyond the lateral. Each tower, which is generally mounted on rubber tires, has a drive device designed to propel the system around the pivot point. The most common power units include electric motor, hydraulic water drive, and hydraulic oil drive. Towers are spaced from 80 to 250 feet apart, and lateral lengths vary up to a half mile. Long spans require substantial trusses or cables to support the elevated lateral pipe. When feasible, agricultural operators are converting from portable sprinkler systems and travelers to install center pivot systems. Many improvements have been made over the years. This includes the corner arm system. Some models contain an added swing lateral unit that extends to reach the corners of a field and retracts to a trailing position when the system is along the field edge. When the corner unit starts, the flow rate to all heads on the lateral is reduced. Overall field distribution uniformity is affected with the corner arm. Typically, 85% of maintenance is spent maintaining the corner arm unit itself. Due to less than adequate maintenance in corner systems operating all the time, total field application uniformity is reduced even further.

In addition, the center pivot has many disadvantages that make uniform application of water extremely difficult. These include:

- The sprinklers near the pivot must be very small to apply water to the small areas near the center of the field. These small sprinklers may have nozzles as small as 1/16 inch.
- A second disadvantage is that the center pivot is a permanent installation.
- They do not work well on slopes and varying terrain. The maximum recommended variation in elevation is 30 to 40 feet.
- They do not irrigate the corners of fields—they were developed to be used on flat, square quarter- or full-sections in the western U.S. They irrigate circular areas very well, but often are not able to irrigate field corners without special equipment.

There are several advantages to using center pivot systems. These include:

- Low labor needed to apply large volumes of water onto large fields.
- Low operating costs including fuel costs if low-pressure drop-tube sprinklers are used.

Many techniques have been developed to reduce the energy used and increase the efficiency of center pivot systems, including lower system flow capacities, and maximize water use efficiency of center pivot systems. These improvements generally fall into one of two categories and include using Low Energy Precision Application (LEPA) and Low Pressure In-Canopy (LPIC) systems.

LEPA systems utilize drop tubes with small radius sprinklers suspended just above the crop canopy. These small radii sprinklers used on LEPA systems can have larger instantaneous application rates, especially in the areas close to the pivot's center. Therefore, these systems often produce the opportunity for surface water ponding and on sloping areas, some runoff, which may yield erosion. LEPA systems are not suitable for use on low intake soils.

LPIC systems utilize drop tubes with small radii spray-type sprinklers suspended below the crop canopy. Like the LEPA systems, these small radii sprinklers can have the ability to larger instantaneous application rates especially in the areas close to the pivot's center. Therefore, these systems often produce the opportunity for surface water ponding and on sloping areas, some runoff, which may yield erosion. LIPC systems are not suitable for use on low intake soils.

With proper management, application efficiencies with center pivot systems can be 75 – 90 percent depending on wind speed and direction, sprinkler type, operating pressure, and tillage practices.

(d.5.a) Planning and design considerations

Center pivot irrigation equipment dealers have access to and can use a computer program, provided by each center pivot system manufacturer, to perform a detailed design specific for the make and model of the pivot being considered. Since pipe size and sprinkler spacing combinations are unique for each manufacturer, this is the only way accurate, detailed designs can be prepared. The grower is generally provided a copy of the sprinkler design package. Evaluating this information is always the first step when providing a field evaluation on a specific pivot system.

(d.5.b) Application Depth

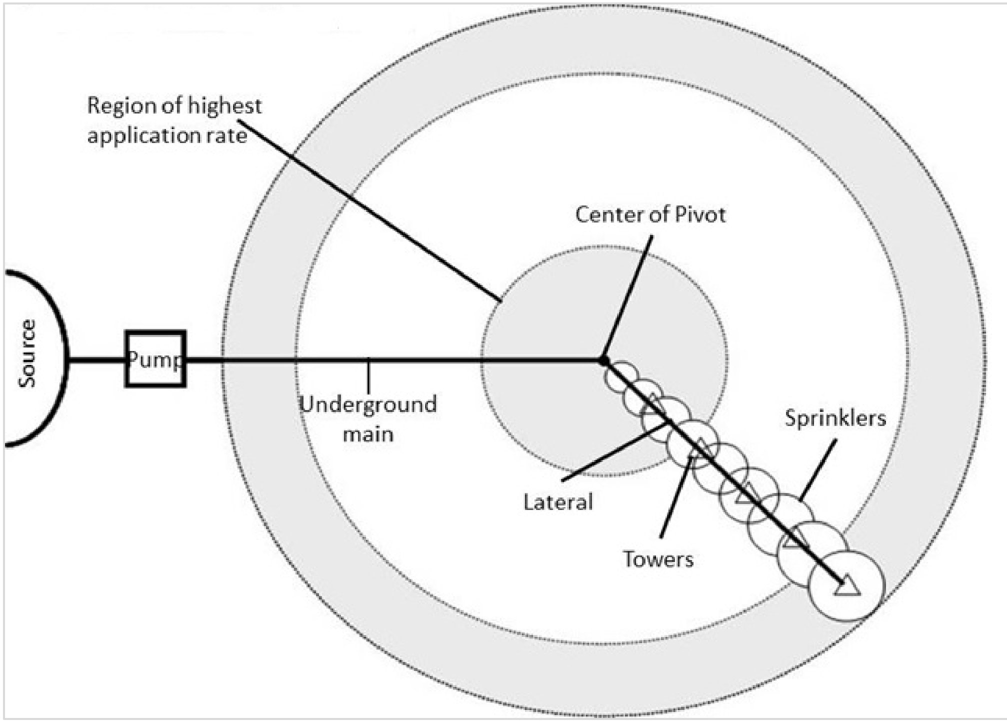
The average depth of water applied during each pass (or rotation) of a center pivot irrigation system can be computed by first determining the pump flow rate to the center pivot, Q in gpm, the time required to make one complete pass (revolution if the center pivot goes full circle), T in hours, and the effective radius, R of the center pivot. The effective radius should be the length of the center pivot's lateral, L, plus the radius, r of the last sprinkler at the very end of the center pivot; thus R = L + r. If these data are available, and it is known how many degrees of arc, φ the center pivot covers in each pass, the depth of water applied, D_a, in inches, during each pass of the center pivot is:

$$D_a = \frac{11000QT}{\varphi R^2} \qquad (6.29)$$

(d.5.c) Application Rate

The system designer is the best source of determining the application rate of a center pivot system. One field method is to place collection buckets at several locations along the length of the pivot and measure the amount of time the buckets receive liquid and the depth they receive. Divide the depth of water by the length of time to calculate the application rate at each bucket location.

Figure 6.13 Center Pivot Irrigation System



The highest rate computed (from all the bucket-positions evaluated) should be used as the application rate for the center-pivot system. This is the application rate that should be less than the soil's infiltration rate if no runoff is to occur.

The following example will show how Equation 6.29 can be used.

Example 6.15: A center pivot irrigation system will be used to irrigate a field of potatoes on a silt loam soil. The pivot lateral is 500 feet long and the total flow rate to the lateral is 600 gpm. The radius of the end gun is 100 ft and the center pivot is designed to make one pass over 200 degrees of arc in 2.7 hrs. Determine the depth of water applied during each.

Solution: The depth of water applied during each revolution can be computed from Equation 6.29 as:

$$D_a = \frac{11000(600)(2.7)}{200(600)^2} = 0.25\ inches$$

Assuming the effective radius is the lateral length of 500 ft plus the 100-ft radius of the end sprinkler.

(e) Microirrigation Systems

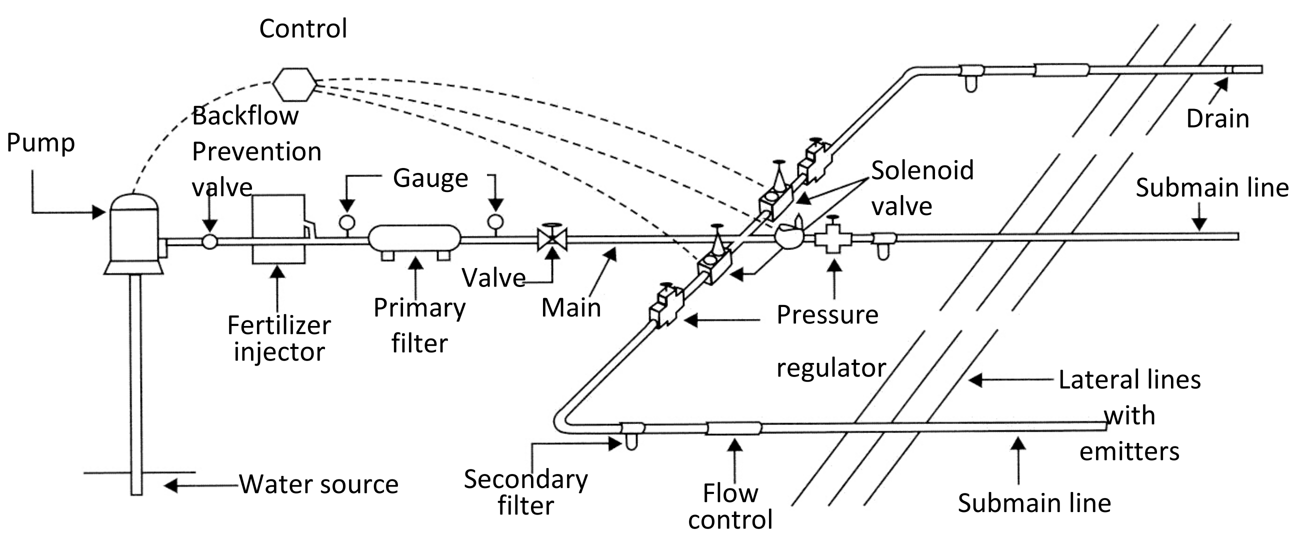
(e.1) General

Microirrigation consists of low volume, low pressure application of water to the soil surface. Microirrigation emission systems can be buried under the soil surface, but this is rarely desirable or practical in Pennsylvania. Emission devices most commonly used in Pennsylvania consist of drip emitters that are either in-line or line-source (integrated inside a tube or tape) emitters or point-source emitters (externally attached to a drip tube), and micro spray sprinkler systems (used primarily in orchards on sandy soils). Microirrigation is also referred to as drip or trickle irrigation.

Water is applied through drip emitters or micro spray heads placed along a water delivery line called a lateral. The outlet device that controls water release rate is called an emitter. Water released from drip emitters falls (or drips) onto and then enters (infiltrates into) the soil. From these point-sources, water moves downward through the soil profile by gravity and laterally toward zones of higher tension (drier areas). The volume and shape of the wetted soil depends on soil characteristics (texture and structure), length of the irrigation application, emitter flow rate, and number and spacing of the emitters. The number and spacing of emitters are dependent on the spacing and size of plants being irrigated and the soil characteristics.

With proper management, application efficiencies for a well-designed, installed, and maintained microirrigation system can be in the range of 80–95%. Proper water management with microirrigation is essential to avoid excessive water use. Deep percolation, typically the result of over-irrigation, cannot be seen. As a result, over-irrigation is by far the biggest problem with users of microirrigation. The irrigation system designer needs to have realistic expectations of water management skills and desires of the user. These considerations will be discussed in Chapter 9.

Figure 6.14 Microirrigation System Components



(e.2) System Components

System components should include the following starting at the water source: (Refer to Figure 6.14)

1. Filtration to remove debris, organic material and coarse sediments. The filters can consist of pre-screening (not shown: i.e. settling pond or coarse screen) and primary filters for filtration of debris, organic material or coarse sediments from surface water, such as sand media filter with automatic backflush, automatic disc filters that backflush with preset pressure differential, to name only a few; or if sand is being pumped from a well, a sand separator.
2. Back flow preventer upstream of chemical injector device or chemigation valve (for injecting fertilizer or other pipeline cleaning chemicals). Can also be located in the zone with the injector device.
3. Pressure gauges and flow meter to measure flow rate and pressure at pump discharge.
4. Filtration system for fine sand and sediment, such as a screen or disk filter. Pressure gauges necessary upstream and downstream of filter.
5. Mainlines: typically, PVC pipe sized for pumping capacity and irrigation water requirements.
6. Submains: typically, PVC pipe with control valves, pressure regulators, drains and air vents as necessary.
7. Lateral lines: typically, surface PE plastic tubing or tape.
8. Emission devices.
9. Automatic flush valves at ends of laterals (not shown).

(e.3) Planning and Design Considerations

(e.3.a) Water Supply – Water quality and quantity is usually the most important consideration when determining whether a microirrigation system is physically feasible. Well water is usually of high quality and can be drip irrigated with minimal filtration. Surface water can contain organic debris, algae, bacteria, soil particles, and other material. In designing a microirrigation system, the water supply first should be tested to properly plan the needed components to prevent emitter clogging. Such items may include sand separators; sand media filters; self-cleaning disc or screen filters; chlorination injections to precipitate iron or other minerals and kill organic material such as algae and bacteria and a good self-cleaning filter to trap precipitate before the water enters the irrigation system; aerators; ionization to control mineral deposits such as scale; backflow preventers to protect water quality if injecting chemicals or fertilizer.

(e.3.b) Clogging – Clogging is the most serious disadvantage of micro irrigation. Properly designed and maintained filtration systems generally protect the system from most clogging. Clogging causes poor water distribution and may damage the crop if emitters are plugged for extended periods. The irrigator must be able to see or know when clogging is occurring to prevent excessive plant stress. Visible signs of soil wetting should be checked, flowmeters and pressure gauges should be checked to detect flow rate and pressure changes, and a system evaluation conducted where flow rates are measured using catch cans and timed with a stop watch. Many of these potential problems are summarized in Tables 6.5 and 6.6.

Table 6.5 Physical, Chemical, Biological Factors Which Cause Plugging of Emitters.

Physical	Chemical	Biological
Organic debris	Calcium or Magnesium carbonates	Filaments
Aquatic weeds, moss	Calcium sulfates, ferric iron	Slimes
Algae	Metal hydroxides, carbonates, silicates, and sulfates	Microbial deposits
Aquatic creatures, snails, fish	Fertilizers, phosphate, ammonia, manganese, iron, zinc, copper	Manganese ochre
Plastic particles		Sulfur ochre
Soil particles, sand, silt, clay		

Table 6.6 Plugging Potential from Irrigation Water used in Micro Irrigation Systems

Problem	Low	Medium	Severe
Physical			
Suspended solids, ppm[1/]	50	50-100	>100
Chemical			
pH	7.0	7.0-8.0	>8.0
TDS, ppm	500	500-2000	>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 [2/]	10,000	10,000-50,000	>50,000

[1/] Parts per Million
[2/] Bacteria populations reflected algae and microbial nutrients.

(e.3.c) Filter Systems – All water must be screened or filtered to some degree before being introduced into a microirrigation system. Water quality, temperature, flow rate, and emitter orifice size determine the type of filter required. Types of filters commonly used in Pennsylvania include screen filters (hand cleaned or self-cleaning); sand media filters (surface water supply or water with high mineral content such as iron); disc filters consisting of a stack of rings in a cylindrical filtering body (automatic back flushing disc filters can be used on surface water filtration); and sand separators.

Design of filtration systems requiring sand media filters shall consider flow rates and filtration during back flushing. Recommended media tank sizes for emitter and row crop drip systems should be based on less than 37 gpm/square foot during back flushing as indicated below in Table 6.7.

Table 6.7 Filter Sizes Required for Various Flow Rates

System Flow Rate (gpm)	Tank Number and Size
50	2 – 18”
100	3 – 18”
150	3 – 24”
200 to 250	3 – 30”
300 to 400	4 – 30”
450 to 550	4 – 36”
600 to 750	3 – 48”
800 to 1000	4 – 48”

Alternative combinations of tank numbers and sizes that produce equivalent filtration areas may be substituted.

(e.3.d) Soil Wetting Patterns – Water distribution and the vertical and horizontal extent of soil wetting from each emitter discharge point should be a major consideration in the design of any microirrigation system.

The volume of soil wetted depends on the emitter type, emitter flow rate, distance between emitters, duration of each application, and soil texture and structure. In general, the diameter of the wetted volume will increase with regulate pressure and limit flow to one direction only (a check valve). Butterfly or wafer valves and ball valves are special geometries of gate valves.

(e.3.f.2) Pressure Regulating, Reducing, and Sustaining Valves –These devises control the pressure within desired limits of emitter discharge.

(e.3.f.3) Vacuum and Air Relief Valves –Air relief valves help prevent pipe water hammer and surge and should be included at high points in the system and at the ends of the manifold or submain. Vacuum relief is necessary to prevent pipe collapse at shut down due to negative pressure in the pipeline. Negative pressure also can result in suction of soil particles into the emitters. These are recommended at the beginning of each drip zone after the control valve. Combination air/vacuum relief valves are generally used on all drip systems.

(e.3.f.4) Flow Meters and Pressure Gauges –Pressure gauges monitor the pressure in the system. Flow meters measure the volume of water passing through a pipe. These devices are good management tools for detection of leaks or clogs in the system. Flow meter should have a straight, unobstructed section of pipe upstream equivalent in length to 5 – 10 times the pipe diameter, and 2 – 4 times the pipe diameter downstream of the flow meter. It should read both the instantaneous flow rate and the totalized volume. Propeller flowmeters are common types used. Styles that are typically used include: tube style- fixed or removable assembly, and bolt on saddle type meters.

(e.3.f.5) Flushing Valves or Flushing Manifolds –Flushing valves and manifolds are recommended to flush sediment or debris from the system. They are commonly included at the end of each lateral line and respond automatically.

(e.3.f.6) Drain Valves –Drain valves are included at the ends of the manifold to drain water from the system to protect buried pipe from freezing.

(e.3.f.7) Backflow Prevention Devices –Back flow prevention devises are designed to protect the water source from back flow contamination (fertilizer injections or water treatment injections), due to back siphonage or back pressure. A common type of device used is a Chemigation Valve which includes the check valve, air vent, drain, and injection port all in one unit. Other types of backflow preventers used to protect water from pollutants include: atmospheric vacuum breakers (AVB), pressure vacuum breakers (PVB), double check valves (DC), and reduced pressure vacuum breakers (RP). To protect against contaminants due to back siphonage and back pressure, only reduced pressure backflow preventers (RP) are reliable.

(e.3.f.8) Injection Systems –There are various ways to inject fertilizer and chemicals into irrigation systems. The choice of method and equipment will depend on the following*:*

- Potential hazard of the chemical (acids or pesticides).
- Injecting liquid versus solid materials (fertilizers and chemicals are either soluble or need to be made soluble before injecting them into the irrigation system).
- Availability of power. If electric is not available, an injector must be powered by water, an internal combustion engine, or other means.
- Portability versus permanent installation.

Storage tanks and stock mixing tanks should be made of materials which can withstand the chemicals put into them. All fittings, pipe, injectors, meters, valves and pumps should be selected based on their ability to handle the chemicals that will be used.

Types of injectors most commonly used include:

Pumps – These include piston, diaphragm, and centrifugal type pumps. Energy sources can be electrical motors, water driven hydraulic motors or internal combustion engines.

Venturi Injectors – These injectors work by drawing in the fertilizer or chemicals through a hole which is located in that portion of the venturi where a negative pressure or suction is created. Chemicals join the stream of water passing through and mixing occurs. Rates can be adjusted and metered by use of valves and flowmeters.

Pressure Differential – Created by placing a valve or restricting device in the supply line. Water upstream of the valve will have a higher pressure than the water downstream. Water is diverted from the upstream side into a closed tank which contains fertilizer or chemicals, passes through taking fertilizer with it, and flows back into the low pressure downstream portion of the supply line.

(e.3.g) Fertigation –The application of plant nutrients through a microirrigation system is convenient and efficient. 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 they may react with salts in the 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.

Costs – Equipment, filtration, control devices, and numerous laterals and emission devices generally can result in a high cost per acre. A technical as well as an economic analysis is essential if maximum profits are to be achieved from drip irrigation. The profitability of an irrigation investment is critically dependent upon engineering estimates of the life expectancy of the equipment, energy usage, maintenance and repairs, level of management, and the effects of a microirrigation system on crop yields.

Maintenance – Frequent maintenance is essential to keep emitters functioning at design flow rates. A good operation and maintenance program is critical to ensure design standard emission uniformity and system efficiency. The following items are recommended:

- Clean or backflush filter systems: This can be done manually or through automated back flushing based on pressure differentials.
- Flush lateral lines regularly. Automatic flush valves can be installed on the end of each line.
- Check emitter discharge rates and replace emitters if clogged.
- Check operating pressure often. A pressure drop or rise may indicate leaks or clogs.
- Inject chemicals as required to prevent precipitate buildup such as iron, iron bacteria slime, and algae growth. Inject liquid fertilizers when needed.
- Check and service pumps regularly.

(e.3.h) Automation –Microirrigation 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 start and stop an irrigation event, can also be designed. This can be applied with an electric pump relay system. Several sensors are recommended, depending on soils and rooting depth of crops grown.

(e.4) Emitter Characteristics

The primary objective of good microirrigation system design and management is to provide sufficient system capacity to adequately meet crop-water needs. Uniform application depends on the uniformity of emitter discharge, system maintenance, and proper design. Non-uniform discharge is caused by the pressure differential from friction losses, elevation change, plugging, and manufacturer variability. Using pressure compensating emitters somewhat alleviates the elevation change and pressure differential problem. Also using multiple emitters per tree, vine, or plant helps to compensate for manufacturing variability, and minimize plant damage that results from plugged or malfunctioning emitters. The designer must make a rational choice about the duration of application, the number of emitters per plant, the specific type of emission device, and the discharge per emitter to provide the most effective irrigation. The pressure differential among all the emitters in a field should be within 20%. This includes the pressure variability throughout laterals, manifolds, and applicator devises.

(e.4.a) Non-Pressure-Compensating and Pressure-Compensating Emitters

Pressure compensating means that over a limited range of line pressures (usually between 5 and 30 psi) the emitter’s flow rate will remain nearly constant. The flow from non-pressure compensating emitters increases as the line pressure increases and vice versa. Pressure compensating emitters are more expensive but help provide a nearly constant flow of water to plants at varying pressures and elevations. Non-pressure compensating emitters are generally less costly and can best be used where drip lines will be laid on a downward slope.

(e.4.b) Line Source Emitters

A line source emitter system consists of a series of equally spaced emission points along a single or double chamber tube. Tubing can consist of polyethylene (PE) plastic in the form of flexible hose, tape, or semi-rigid tubing that retains its shape. The emitters are normally spaced at intervals of 8, 12, 18, 24, and up to 60 inches along the lateral. The line-source flow rates vary from 0.1 to 1.0 gallons per hour per emitter or 1 to 1.0 gallon per minute for every 100 feet of dripline depending on the spacing between emitters. The required operating pressure ranges from 2 to 30 psi, with pressures of 10 to 15 psi being most common. Line source emitters may be non-pressure compensating or pressure compensating. Line source emitters are usually best for small fruits, including strawberries, blueberries, blackberries, and raspberries. Line source emitters also work well for vegetables and row crops.

(e.4.c) Point Source Emitters

A point source emitter is an individual emitter, located outside of, and connected directly to the supply pipe or connected to the supply pipe by a small-diameter PE tube. Water leaves each emitter as discrete or continuous drops or tiny streams. 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 gph to nearly 3.0 gph for individual point source drip emitters. Point source systems operate under somewhat higher pressures than line source systems; ranging from 10 to 30 psi. Water pressure is dissipated within the point source emitter to achieve a low flow rate; water may flow through a long narrow path, a vortex chamber, small orifice or other arrangement before discharging.

Some emitters are self-flushing, but all point-source systems require water filtration. Follow the manufacturer's filtration requirements. The point source emitter is typically used on tree fruit crops, and ornamental trees and shrubs, where larger plants are widely spaced. It is also used for container-grown nursery or greenhouse crops.

(e.4.d) Low Pressure Spray Heads

A third type of microirrigation system is the micro sprinkler which applies water as spray droplets from small low-pressure heads. Typical wetted diameters can range from 2 to 8 feet for short range nozzles to up to 26 feet for long range nozzles. Discharge rates generally range from 5 gph to 25 gph. The wetted pattern is larger than that of typical drip emitter devices, and generally fewer application devices are needed per plant. Low pressure spray heads work well with most tree fruits, especially on sandy soils. The micro sprinkler system has the advantage of wetting more of the root zone area than single emitters. Micro sprinkler spray application patterns can be 360 degrees (full coverage – place between trees so trunk is not directly wetted); 180 degrees (half circle); or partial circle (both sides). If a micro spray sprinkler is placed at the trunk of the tree a stream splitter should be considered to prevent wetting the trunk. This will block the water flow with a 30 degrees notch around the trunk. If an orifice becomes plugged it is easily removed, cleaned, or replaced.

(e.5) Emitter Performance and Selection

Before a specific emitter can be selected, there is a need to more fully understand some of the differences between a typical sprinkler system and a drip system. With drip irrigation systems the time/set, T_s, sets/day, S_d, and sets/cycle, S_w, are often viewed differently. Instead of considering one application of water every irrigation interval, II, irrigators often think in terms of applying the needed water more often. Many drip irrigators will apply the water needed by the plants every day or every other day. This means the drip system may be used to apply smaller depths of water more frequently. The required system discharge for a specified area to be irrigated, A in square feet, at an application depth, D_d in inches per application, over a period of application, H_a, in hours can be computed as:

$$Q = \frac{A(D_d)}{1.6H_a} \qquad (6.30)$$

where Q is in units of gallons per hour per the area evaluated. The following examples will show how this relationship can be used to determine the required emitter flow rate.

Example 6.16 Develop a management scheme for the potato example introduced earlier (Example 6.3 Figure 6.1). Assume the potatoes will be drip irrigated every other day, the soil is Clymer.

Solution: In this example consider applying (0.2/0.9) = 0.22 inches of water every day, thus the whole field will be irrigated every day, as one set. Or, in this case, applying 0.44 inches of water every two days, thus half of the field will be irrigated every day; the whole field will be irrigated on a 2-day schedule.

Example 6.17 Select a pressure compensating, line-source emitter to provide irrigation to the potato field in Example 6.16. The rows of potatoes are 3 feet apart and they run across the slope from east to west. Under full growth conditions, assume full canopy (each row is 3 feet wide). There should be two sets (or zones). Set 1 will be irrigated every other day. Likewise Set 2 will be irrigated on alternate days. Actual irrigation must be limited to 12 hrs/day.

Solution: First determine the needs of each individual row of potatoes. Each row is 3 feet wide and 300 feet long, which yields an area/row of 900 ft^2. Or, in preparation for looking at data supplied by a drip tape supplier, this is 300 ft^2/100 feet of length (Area on a 100-ft basis). At 0.44 inches (D_d) of water depth to be applied in a maximum of 12 hours (H_a), yields a minimum drip tape flow rate (using the Equation 6.30) of:

$$Q = \frac{A(D_d)}{1.6H_a} = \frac{300(0.44)}{1.6(12)} = 6.88 \text{ gph/100 feet} = 0.114 \text{ gpm/100 feet}$$

Before an appropriate drip tape can be selected, it is necessary to decide what emitter spacing would work best for this application. Since our soil is Clymer, which is a silt loam, Table 6.8 shows that a single emitter will wet a circle that is 5 feet in diameter. Therefore, to choose an emitter spacing of 3 or 4, or even 5 feet would work well. However, because the effective root depth is only 18 inches, the drip emitters should not to be spaced more than 2 feet apart.

A manufacturer's drip catalog must be examined with a desire to locate a line-source drip tape with pressure compensating emitters spaced between 1.5 and 3 feet apart with a flow rate of 6.9 gph/100 feet or 0.114 gpm/100 feet or an equivalent.

(e.6) Steps to Designing a Microirrigation System

The steps to designing a microirrigation system are essentially the same as were presented for designing a sprinkler system; see Chapter 1, section e. The system spacing and the emitter selection steps are somewhat different, but as before, the design should proceed from the plant(s) growing in the field to be irrigated to the water supply.

(e.7) Drip Irrigation with Line-Source Emitters

The design procedure and an example for a drip irrigation system using line-source emitters are presented in Appendix E.

(e.8) Drip Irrigation with Point-Source Emitters

An example design procedure for a drip irrigation system using point-source emitters is presented in Appendix F.

(e.9) Microsprinklers or Low-Pressure Spray Heads

In recent years, the irrigation industry has developed low-pressure spray heads that can be used as an alternative to point-source emitters. These spray heads work well under fruit trees. They operate at essentially the same pressure as point-source emitters, but because they spray water over a larger area (under the tree) the tree's root volume is better supplied with irrigation water.

A specific example of how this system should be designed has not been included. Instead, consider the example presented in Appendix F as if, instead of locating 13 point-source emitters under each tree, these 13 emitters are replaced with 2 low-pressure spray heads each with a flow rate of 10 gph at 20 psi. These spray heads throw water in a 2- to 3-foot diameter. Therefore, the lateral flow rate and size should be the same as in the example provided in Appendix F. And the main, pump and suction pipe should also be the same.

Chapter 9 Irrigation Water Management -- 652.0907 PA State Supplement

(a) General

Irrigation water management is the act of timing and regulating irrigation water applications in a way that will satisfy the water requirement of the crop without wasting water and includes taking advantage of the water applied by natural precipitation. It means applying water according to crop needs in amounts that can be held in the soil available to crops.

Effective management is an important factor in the success of an irrigation system. Large investments in irrigation hardware, large quantities of water, and often large labor inputs, are required for irrigation. The irrigator can realize profits from investments in irrigation equipment only if water is used efficiently.

The net results of proper irrigation water management typically:

- Prevent excessive use of water for irrigation purposes
- Reduce labor
- Minimize pumping costs
- Increase crop biomass yield and product quality

Tools, aids, practices, and programs to assist the irrigator in applying proper amounts of irrigation water include:

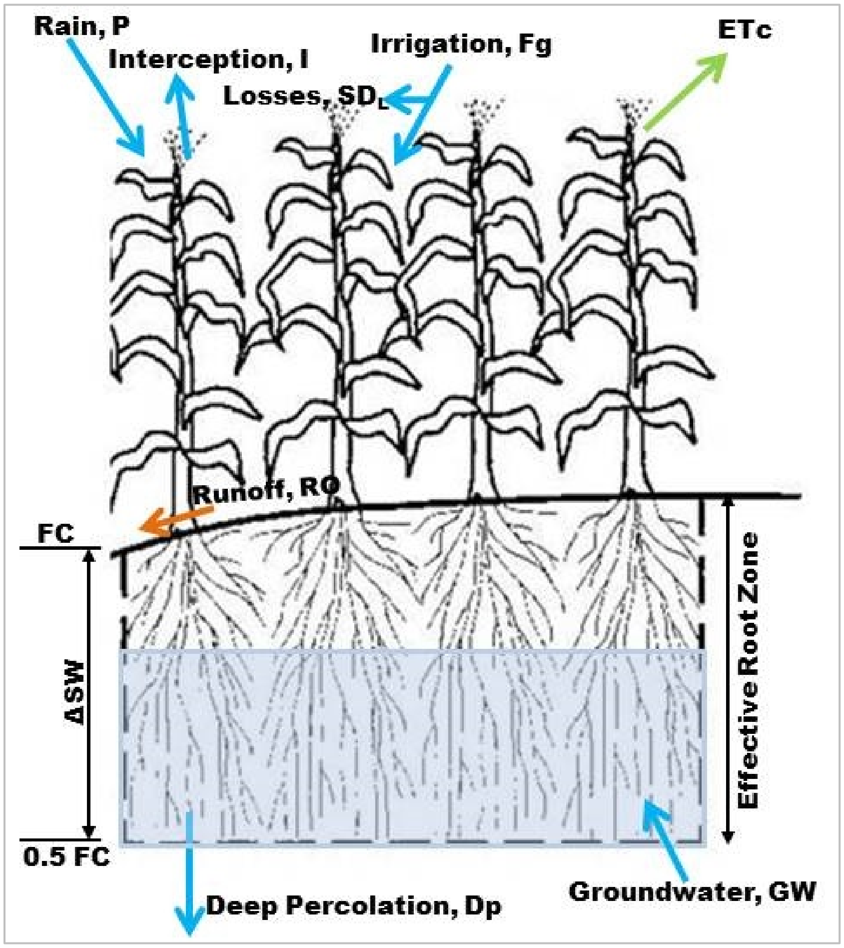
- Using water budgets or water balances to identify potential water application improvements.
- Applying the knowledge of soil characteristics for water release and available water capacity
- Applying the knowledge of crop characteristics for water use rates, growth characteristics, yield and quality, rooting depths, and allowable plant moisture stress levels.
- Irrigation scheduling techniques
- Irrigation system evaluation techniques

(b) Soil-Plant-Water Balance

The soil-plant-water balance is described as the daily accounting of water availability to the crop within its effective root depth.

Many methods and associated programs have been developed to assist irrigators in making two important decisions; (1) when should irrigation water be applied? And (2) how much water should be applied? To understand how to fully answer these questions the irrigation decision maker must develop a detailed understanding of (a) the water requirements of the crop being grown, (b) the soil, especially the effective root depth and the root's ability to take in and store water the crop will utilize, and (c) the local climate.

Figure 9.1 Diagram of a growing crop's soil-water balance



The components of a soil-water balance (or budget) analysis must include all water going into the effective root depth and all water leaving the effective root depth during the time period being considered see Figure 9.1. The basic purpose of this analysis is to determine the location of all water related to growing the crop in question. A soil-water balance can be determined for a day, a week, a month, a growing season, a year or more. For our purposes, the soil water balance will (or should) be set up to be evaluated on a daily basis. This means that the inputs to the soil-water balance must be available and known on a daily basis. The soil-water balance should be applied to the crop's effective root depth and can be shown in Equation form as:

$$Fg = ET + Aw + Dp + RO + SDL - P - GW - \Delta SW \quad (9.1)$$

Where:

ET	= Crop evapotranspiration during the period. Rarely are the data available to permit computation of daily ET rates for crops using the Penman-Monteith method. The alternative is to assume the daily ET rate is equal to the design ET rate for Pennsylvania (0.20 inches/day). These results give a reasonable estimate of how much water the crop is expected to withdraw from the effective root depth on a daily basis.
Dp	= Deep percolation during the period. Deep percolation refers to water that drains downward out of the bottom of the root zone when the root zone water content has been raised above field capacity. Deep percolation occurs when too much irrigation water has been applied bringing the root-zone water content above field capacity or when it rains enough to bring the root zone water content above field capacity. One of the reasons why this soil-water balance is evaluated is to prevent over irrigation, thus deep percolation from applied irrigation water should always be zero.
SDL	= The combination of various spray, drift losses, and crop canopy interception during the period. These losses are essentially the losses accounted for when a water application efficiency (WAE) is selected for the method of irrigation being used. When a sprinklers system is designed, the WAE = 70% is assumed, thus we are assuming that 30% of the water applied will be lost and never reach the effective root depth. For drip systems, these losses are smaller; normally 5 to 10%. These losses are accounted for in the system design and should not need to be considered in this analysis.
GW	= Groundwater contribution to the root zone during the period. When the field being cropped and irrigated has a water table located near the bottom of the root zone, the process called capillary rise may lift some of the water stored in the water table upwards into the root zone. This is a rare occurrence in Pennsylvania soils and can usually be ignored in the soil-water balance.

ΔSW	= Change in soil-water content within the effective root depth during the period. The goal of soil-water management during the growing season of a crop is to manage the soil-water in the effective root depth. This means the soil water content in the effective root depth should in generally not be allowed to drop below the point where half of the AWC has been used. It should also mean that the effective root depth soil-water content should be managed so that the soil water content never rises above field capacity. Thus, there is a rather narrow range of soil-water contents that foster healthy, vigorous crop growth. Irrigation is the tool growers often use to manage the level of soil-water so (a) the crop does not experience water stress (it is too dry – more than half of the AWC has been used), (b) or the soil is too wet (the soil-water content is above field capacity).

(c) Daily Assessment Process.
To be able to assess a specific crop growing in a specific soil in a specific climate on a daily basis so irrigation decisions can be made on a daily basis is a very complex procedure. In fact, to do this proposed assessment by hand, or with a simple calculator would require a great deal of work.

Consequently, designers and those servicing the irrigation industry have developed computer programs designed to do the necessary computations and provide realistic guidance to the irrigation decision maker. Any of these programs should be helpful to the irrigator if the required data are available.

(d) Measuring Soil Water Content
There are other approaches to monitoring or managing irrigation systems. One of those is to actually measure the water content in the effective root depth of the crop. Another is the measure of the soil-water tension in the soil.

These various methods are outlined, in detail in Part 652 Chapter 9 of the National Engineering Handbook Irrigation Guide which can be used to help in deciding when and how much water to apply through any irrigation system.

(e) Irrigation System Evaluations
There may be occasions when NRCS personnel are called to a client's property and asked to evaluate, or help evaluate an existing irrigation system. There are a number of approaches and tools available for deciding if changes are needed to improve the operation of an irrigation system. These methods are outlined in detail in Part 652 Chapter 9 of the National Engineering Handbook Irrigation Guide.

APPENDIX A
Notes for IWRpm use and data entry for Pennsylvania

General

IWRpm is a NRCS Irrigation Water Requirement program. This program is an implementation of certain procedures for computing monthly and seasonal irrigation water requirements. The procedures used in this program are generally as detailed in the United States Department of Agriculture (USDA)- Natural Resources Conservation Service (NRCS) National Engineering Handbook (NEH), Part 623, Chapter 2 – Irrigation Water Requirements, September 1993, also called NEH2.

Reference

NRCS, Irrigation Water Requirements Penman-Monteith (IWRpm) User manual, Version 1.1 dated September 13, 2006. (CCE compliant)

Climate

1. Basic climate data must be downloaded for Pennsylvania. The temperature and precipitation data is already loaded on the national NRCS software site, and the NRCS agency contact for irrigation (Irrigation Engineer WNTC, Portland, Oregon) can provide guidance through the download process to direct the national data for Pennsylvania to transfer for Pennsylvania applications of the IWRpm software.

2. The national NRCS data supplied partial weather station data for 72 Pennsylvania weather stations, however wind speed, humidity, and sunshine data were not provided and the software suggests this to be acquired. Use the “edit database” function.

3. The Northeast Regional Climate Center website was used to retrieve additional supplemental weather data from the following seven representative weather station sites across Pennsylvania: Erie, Pittsburgh, Ridgway, Williamsport, Avoca, Middletown, and Philadelphia. The Northeast Regional Climate Center only listed the supplemental data for those 7 Pennsylvania weather stations, not all 72. The following supplemental data were retrieved and entered into the IWRpm software:

- **a.** Average historical monthly wind speed.
- **b.** Average historical monthly relative humidity, minimum (PM) and maximum (AM).
- **c.** Average historical monthly percent of possible sunshine. This number was multiplied by the average hours of daylight per month to determine the historical monthly average duration of sunshine in hours per day.

4. One of the seven representative stations with the full data was selected to be connected by association to each of the 72 weather stations in Pennsylvania. Normally the closest weather station was selected.

5. Trial computations for crop irrigation water needs were run using all 72 Pennsylvania weather stations. Based on these crop irrigation needs trial computations, three climatic regions for Pennsylvania were chosen: North, Central, and Southeast. The three regions/zones are shown on Figure 4.2. The Central region covers a large section of the state stretching from west to east and south. The Northern region generally requires 10% less irrigation water than the Central region and the Southeast region generally requires about 10% more irrigation water than the Central region.

6. The Ridgway, PA weather station is very similar to the average net irrigation outcome for the North Region and was used to develop the yearly net irrigation table for the entire North Region. Lebanon, PA was used to develop the net irrigation table data for the entire Central Region, and the Octorara, PA weather station was used for the entire Southeast Region, as these stations best match the average needs for these two regions.

7. Some of the tables and figures of the PA Irrigation Guide were derived from the IWRpm software. The PA Irrigation Guide is intended to present net irrigation water needs for selected crops without the use of the IWRpm software. The IWRpm software can be used by a designer for a specific climate or location irrigation applications or other special design adaptations on an as-needed basis.

Crops

1. In preparing the net water depth needs for the PA Irrigation Guide IWRpm Local Crop Database, a list of 19 crops was selected to be representative of crops irrigated in PA.

2. The estimated growth dates for crops grown in PA for each crop were added into IWRpm from Table 4.3. These estimated growth dates can be adjusted on a case by case or for site specific situations.

3. The spring beginning growth temperature of 50^0 F and fall end growth temperature of 45^0 F for each crop was added into IWRpm. This information is used only if the estimated growth dates are not provided.

4. For each crop in PA the box was checked for "humid with moderate wind".

5. Pennman-Monteth Method, NEH 2, Bas Crop Curves was used for each crop/climate calculation.

6. If information for an additional crop is desired:
   - **a.** Select a similar crop for the irrigation calculations or
   - **b.** Obtain crop information from an irrigation guide from a neighboring state or
   - **c.** Use the IWRpm software to develop the additional cropping information.

7. These general parameters are suggested to be used to calculate the net irrigation water needs for Pennsylvania. The crop portion of the PA Irrigation Guide is intended to allow for the design of irrigation water needs without the use of the IWRpm software. IWRpm software can be used by a designer for very specific crop irrigation applications or other special design adaptations on an as-needed basis.

APPENDIX B
PIPE FRICTION CHARTS

There are two fundamental approaches to determining friction in a pipeline. The first is to go back to one of the friction theories, to compute friction from the basic pipe parameters--pipe diameter, flow velocity, internal roughness, pipe length, etc. The second, and most commonly used approach in engineering practice, is to use friction charts such as the ones presented on the following pages. Each of these friction charts was developed by applying the Hazen-Williams formula, to the various pipe parameters. The shaded areas are not recommended for design use. A variety of tables of common pipe materials and sizes were selected for this guide for ease of use for the design examples, if additional charts are needed for site specific designs, request from pipe suppliers.

The following parameters are presented in each chart:

a. Pipe type

b. Pipe diameter, nominal size and actual I.D.

c. Flow velocity as a function of pipe discharge

d. Friction factor, in units of psi/100 ft, as a function of pipe discharge

The data presented on each of the pipe friction charts is generally the same. These are summarized below with sources:

a. Table B-1, PVC Class 160, SDR = 26, Hazen-Williams "C" = 150

b. Table B-2, PVC Class 200, SDR = 21, Hazen-Williams "C" = 150

c. Table B-3, PVC Schedule 40, Hazen-Williams "C" = 150

d. Table B-4, Aluminum pipe with Couplers, Hazen-Williams "C" = 130

e. Table B-5, Standard Steel-Schedule-40, Hazen-Williams "C" = 100

f. Table B-6, PE, Hazen-Williams "C" = 140

g. Table B-7, Asbestos-Cement, Hazen-Williams "C" = 140

h. Table B-8, Small Diameter PE & Lay flat Hose

Table B-1 Friction Loss Characteristics for PVC Class 160 Pipe

PVC CLASS 160											
PVC CLASS 160 IPS PLASTIC PIPE (1120, 1220) SDR 26; C = 150											
FRICTION LOSS CHARACTERISTICS											
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)											
I.D.	1.195in		1.532in		1.754in		2.193in		2.655in		**I.D.**
Nominal	**1.00in**		**1.25in**		**1.50in**		**2.00in**		**2.50in**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1	0.28	0.02	0.17	0.01	0.13	0.00					**1**
2	0.57	0.06	0.34	0.02	0.26	0.01	0.16	0.00			**2**
4	1.14	0.23	0.69	0.07	0.53	0.04	0.33	0.01	0.23	0.00	**4**
6	1.71	0.49	1.04	0.15	0.79	0.08	0.50	0.03	0.34	0.01	**6**
8	2.28	0.84	1.39	0.25	1.06	0.13	0.67	0.04	0.46	0.02	**8**
10	2.85	1.27	1.73	0.38	1.32	0.20	0.84	0.07	0.57	0.03	**10**
15	4.28	2.71	2.61	0.81	1.98	0.42	1.26	0.14	0.86	0.06	**15**
20	5.71	4.59	3.47	1.37	2.65	0.71	1.69	0.24	1.15	0.09	**20**
25	7.14	6.96	4.34	2.08	3.31	1.07	2.11	0.36	1.44	0.14	**25**
30	8.57	9.74	5.21	2.91	3.97	1.50	2.54	0.51	1.73	0.20	**30**
35	9.99	12.95	6.08	3.87	4.64	2.00	2.96	0.68	2.02	0.27	**35**
40	11.42	16.59	6.95	4.95	5.30	2.56	3.39	0.86	2.31	0.34	**40**
45	12.85	20.63	7.82	6.16	5.96	3.19	3.81	1.08	2.60	0.42	**45**
50	14.28	25.07	8.69	7.49	6.63	3.88	4.24	1.31	2.89	0.52	**50**
55	15.71	29.91	9.56	8.93	7.29	4.62	4.66	1.56	3.18	0.62	**55**
60	17.14	35.14	10.43	10.49	7.95	5.43	5.09	1.83	3.47	0.72	**60**
65	18.57	40.75	11.29	12.17	8.62	6.30	5.51	2.12	3.76	0.84	**65**
70	19.99	46.76	12.16	13.96	9.28	7.23	5.93	2.44	4.05	0.96	**70**
75			13.03	15.86	9.94	8.21	6.36	2.77	4.34	1.09	**75**
80			13.90	17.88	10.60	9.25	6.78	3.12	4.63	1.23	**80**
85			14.77	20.00	11.27	10.35	7.21	3.49	4.91	1.38	**85**
90			15.64	22.23	11.93	11.51	7.63	3.88	5.20	1.53	**90**
95			16.51	24.58	12.59	12.72	8.05	4.29	5.49	1.69	**95**
100			17.38	27.03	13.26	13.99	8.48	4.72	5.78	1.86	**100**
110			19.12	32.24	14.58	16.69	9.33	5.63	6.36	2.22	**110**
120					15.91	19.61	10.18	6.61	6.94	2.61	**120**
130					17.24	22.74	11.02	7.67	7.52	3.03	**130**
140					18.56	26.09	11.87	8.80	8.10	3.47	**140**
150					19.89	29.64	12.72	10.00	8.68	3.94	**150**
160							13.57	11.27	9.26	4.45	**160**
170							14.42	12.61	9.83	4.97	**170**
180							15.27	14.02	10.41	5.53	**180**
190							16.11	15.49	10.99	6.11	**190**
200							16.96	17.03	11.57	6.72	**200**
250									14.47	10.16	**250**
300									17.36	14.24	**300**
350											**350**
400											**400**
500											**500**
600											**600**

Table B-1 (Cont'd). Friction Loss Characteristics for PVC Class 160 Pipe

PVC CLASS 160										
PVC CLASS 160 IPS PLASTIC PIPE (1120, 1220) SDR 26; C = 150										
FRICTION LOSS CHARACTERISTICS										
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)										
I.D.	3.230in		3.692in		4.154in		5.133in			**I.D.**
Nominal	**3.00in**		**3.50in**		**4.00in**		**5.00in**			**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc		**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi		**Gpm**
1										**1**
2										**2**
4										**4**
6	0.23	0.00								**6**
8	0.31	0.01								**8**
10	0.39	0.01	0.29	0.01						**10**
15	0.58	0.02	0.44	0.01						**15**
20	0.78	0.04	0.59	0.02	0.47	0.01				**20**
25	0.97	0.06	0.74	0.03	0.58	0.02				**25**
30	1.17	0.08	0.89	0.04	0.70	0.02	0.46	0.01		**30**
35	1.36	0.10	1.04	0.05	0.82	0.03	0.54	0.01		**35**
40	1.56	0.13	1.19	0.07	0.94	0.04	0.61	0.01		**40**
45	1.75	0.16	1.34	0.09	1.06	0.05	0.69	0.02		**45**
50	1.95	0.20	1.49	0.10	1.18	0.06	0.77	0.02		**50**
55	2.15	0.24	1.64	0.12	1.30	0.07	0.85	0.02		**55**
60	2.34	0.28	1.79	0.15	1.41	0.08	0.92	0.03		**60**
65	2.54	0.32	1.94	0.17	1.53	0.09	1.00	0.03		**65**
70	2.73	0.37	2.09	0.19	1.65	0.11	1.08	0.04		**70**
75	2.93	0.42	2.24	0.22	1.77	0.12	1.16	0.04		**75**
80	3.12	0.47	2.39	0.25	1.89	0.14	1.23	0.05		**80**
85	3.32	0.53	2.54	0.28	2.00	0.16	1.31	0.06		**85**
90	3.51	0.59	2.69	0.31	2.12	0.17	1.39	0.06		**90**
95	3.71	0.65	2.84	0.34	2.24	0.19	1.47	0.07		**95**
100	3.91	0.72	2.99	0.37	2.36	0.21	1.54	0.08		**100**
110	4.30	0.86	3.29	0.45	2.60	0.25	1.70	0.09		**110**
120	4.69	1.01	3.59	0.52	2.83	0.30	1.85	0.11		**120**
130	5.08	1.17	3.89	0.61	3.07	0.34	2.01	0.12		**130**
140	5.47	1.34	4.19	0.70	3.31	0.39	2.16	0.14		**140**
150	5.86	1.52	4.48	0.79	3.54	0.45	2.32	0.16		**150**
160	6.25	1.71	4.78	0.89	3.78	0.50	2.47	0.18		**160**
170	6.64	1.92	5.08	1.00	4.01	0.56	2.63	0.20		**170**
180	7.03	2.13	5.38	1.11	4.25	0.63	2.78	0.22		**180**
190	7.43	2.35	5.68	1.23	4.49	0.69	2.94	0.25		**190**
200	7.82	2.59	5.98	1.35	4.72	0.76	3.09	0.27		**200**
250	9.77	3.91	7.48	2.04	5.91	1.15	3.87	0.41		**250**
300	11.73	5.49	8.97	2.86	7.09	1.61	4.64	0.58		**300**
350	13.68	7.30	10.47	3.81	8.27	2.15	5.41	0.77		**350**
400	15.64	9.35	11.97	4.88	9.45	2.75	6.19	0.98		**400**
500	19.55	14.13	14.96	7.37	11.82	4.15	7.74	1.48		**500**
600			17.95	10.33	14.18	5.82	9.29	2.08		**600**

Table B-2 Friction Loss Characteristics for PVC Class 200 Pipe

PVC CLASS 200											
PVC CLASS 200 IPS PLASTIC PIPE (1120, 1220) SDR 21; C = 150											
FRICTION LOSS CHARACTERISTICS											
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)											
I.D.	0.930in		1.189in		1.502in		1.720in		2.149in		**I.D.**
Nominal	**0.75in**		**1.00in**		**1.25in**		**1.50in**		**2.00 in.**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1	0.47	0.06	0.28	0.02	0.18	0.01	0.13	0.00			**1**
2	0.94	0.22	0.57	0.07	0.36	0.02	0.27	0.01			**2**
4	1.89	0.79	1.15	0.24	0.72	0.08	0.55	0.04	0.35	0.01	**4**
6	2.83	1.68	1.73	0.51	1.08	0.16	0.82	0.08	0.53	0.03	**6**
8	3.77	2.85	2.30	0.86	1.44	0.28	1.10	0.14	0.70	0.05	**8**
10	4.72	4.31	2.88	1.30	1.80	0.42	1.37	0.22	0.88	0.07	**10**
15	7.08	9.18	4.32	2.77	2.72	0.89	2.06	0.46	1.32	0.15	**15**
20	9.43	15.58	5.77	4.71	3.61	1.51	2.75	0.78	1.76	0.26	**20**
25	11.80	23.58	7.21	7.12	4.52	2.29	3.44	1.18	2.20	0.40	**25**
30	14.15	33.00	8.65	9.98	5.42	3.20	4.13	1.66	2.65	0.56	**30**
35	16.51	43.91	10.10	13.27	6.32	4.26	4.82	2.20	3.09	0.75	**35**
40	18.87	56.23	11.54	17.00	7.23	5.45	5.51	2.82	3.53	0.95	**40**
45			12.98	21.14	8.13	6.78	6.20	3.51	3.97	1.19	**45**
50			14.42	25.70	9.04	8.24	6.89	4.26	4.41	1.44	**50**
55					9.94	9.83	7.58	5.09	4.85	1.72	**55**
60					10.85	11.55	8.27	5.97	5.30	2.02	**60**
65					11.75	13.40	8.96	6.93	5.74	2.35	**65**
70					12.65	15.37	9.65	7.95	6.18	2.69	**70**
75					13.56	17.47	10.34	9.03	6.62	3.06	**75**
80					14.46	19.68	11.03	10.18	7.06	3.44	**80**
85					15.37	22.02	11.72	11.39	7.50	3.85	**85**
90							12.41	12.66	7.95	4.28	**90**
95							13.10	13.99	8.39	4.74	**95**
100							13.79	15.39	8.83	5.21	**100**
110							15.17	18.36	9.71	6.21	**110**
120							16.54	21.57	10.60	7.30	**120**
130									11.48	8.47	**130**
140									12.36	9.71	**140**
150									13.25	11.04	**150**
160									14.13	12.44	**160**
170									15.01	13.91	**170**
180									15.90	15.47	**180**
190									16.78	17.10	**190**
200									17.66	18.80	**200**
250											**250**
300											**300**
350											**350**
400											**400**
500											**500**
600											**600**

Table B-2 (Cont'd). Friction Loss Characteristics for PVC Class 200 Pipe

PVC CLASS 200											
PVC CLASS 200 IPS PLASTIC PIPE (1120, 1220) SDR 21; C = 150											
FRICTION LOSS CHARACTERISTICS											
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)											
I.D.	2.601in		3.166in		4.072in		5.133in		5.993 in.		**I.D.**
Nominal	**2.50in**		**3.00in**		**4.00in**		**5.00in**		**6.00 in**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1											**1**
2											**2**
4	0.24	0.01									**4**
6	0.36	0.01									**6**
8	0.48	0.02	0.32	0.01							**8**
10	0.60	0.03	0.40	0.01							**10**
15	0.90	0.06	0.60	0.03	0.36	0.01					**15**
20	1.20	0.10	0.81	0.04	0.49	0.01					**20**
25	1.60	0.16	1.01	0.06	0.61	0.02					**25**
30	1.80	0.22	1.22	0.09	0.73	0.02	0.46	0.01			**30**
35	2.11	0.29	1.42	0.11	0.86	0.03	0.54	0.01			**35**
40	2.41	0.38	1.62	0.14	0.98	0.04	0.61	0.01			**40**
45	2.71	0.47	1.83	0.18	1.10	0.05	0.69	0.02			**45**
50	3.01	0.57	2.03	0.22	1.23	0.06	0.77	0.02			**50**
55	3.31	0.68	2.23	0.26	1.35	0.08	0.85	0.02			**55**
60	3.61	0.80	2.44	0.31	1.47	0.09	0.92	0.03	0.68	0.01	**60**
65	3.92	0.93	2.64	0.36	1.59	0.10	1.00	0.03	0.73	0.02	**65**
70	4.22	1.06	2.84	0.41	1.72	0.12	1.08	0.04	0.79	0.02	**70**
75	4.52	1.21	3.05	0.46	1.84	0.14	1.16	0.04	0.85	0.02	**75**
80	4.82	1.36	3.25	0.52	1.96	0.15	1.23	0.05	0.90	0.02	**80**
85	5.12	1.52	3.45	0.59	2.09	0.17	1.31	0.06	0.96	0.03	**85**
90	5.42	1.69	3.66	0.65	2.21	0.19	1.39	0.06	1.02	0.03	**90**
95	5.72	1.87	3.86	0.72	2.33	0.21	1.47	0.07	1.07	0.03	**95**
100	6.03	2.06	4.07	0.79	2.46	0.23	1.54	0.08	1.13	0.04	**100**
110	6.63	2.45	4.47	0.94	2.70	0.28	1.70	0.09	1.24	0.04	**110**
120	7.23	2.88	4.88	1.11	2.95	0.33	1.85	0.11	1.36	0.05	**120**
130	7.84	3.34	5.29	1.29	3.19	0.38	2.01	0.12	1.47	0.06	**130**
140	8.44	3.84	5.69	1.47	3.44	0.43	2.16	0.14	1.59	0.07	**140**
150	9.04	4.36	6.10	1.68	3.69	0.49	2.32	0.16	1.70	0.08	**150**
160	9.64	4.91	6.51	1.89	3.93	0.55	2.47	0.18	1.81	0.08	**160**
170	10.25	5.50	6.91	2.11	4.18	0.62	2.63	0.20	1.93	0.09	**170**
180	10.85	6.11	7.32	2.35	4.42	0.69	2.78	0.22	2.04	0.11	**180**
190	11.45	6.75	7.73	2.60	4.67	0.76	2.94	0.25	2.15	0.12	**190**
200	12.06	7.43	8.14	2.85	4.92	0.84	3.09	0.27	2.27	0.13	**200**
250	15.07	11.23	10.17	4.31	6.15	1.27	3.87	0.41	2.83	0.19	**250**
300	18.09	15.74	12.21	6.05	7.38	1.78	4.64	0.58	3.40	0.27	**300**
350			14.24	8.05	8.61	2.36	5.41	0.77	3.97	0.36	**350**
400			16.28	10.30	9.84	3.03	6.19	0.98	4.54	0.46	**400**
500					12.30	4.58	6.96	1.48	5.67	0.70	**500**
600					14.76	6.42	9.29	2.08	6.81	0.98	**600**

Table B-3 Friction Loss Characteristics for PVC Schedule 40 Pipe

PVC SCHEDULE 40											
PVC SCHEDULE 40 IPS PLASTIC PIPE (1120, 1220); C = 150											
FRICTION LOSS CHARACTERISTICS											
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)											
I.D.	0.622		0.824in		1.049in		1.380in		1.610in		**I.D.**
Nominal	**0.50in**		**0.75in**		**1.00in**		**1.25in**		**1.50in**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1	1.05	0.43	0.60	0.11	0.37	0.03	0.21	0.01			**1**
2	2.11	1.55	1.20	0.39	0.74	0.12	0.42	0.03	0.31	0.02	**2**
4	4.22	5.60	2.40	1.42	1.48	0.44	0.85	0.12	0.62	0.05	**4**
6	6.33	11.86	3.60	3.02	2.22	0.93	1.28	0.25	0.94	0.12	**6**
8	8.44	20.20	4.80	5.14	2.96	1.59	1.71	0.42	1.25	0.20	**8**
10	10.55	30.54	6.00	7.77	3.70	2.40	2.14	0.63	1.57	0.30	**10**
15			9.00	16.52	5.61	5.10	3.21	1.35	2.35	0.63	**15**
20			12.01	28.04	7.41	8.66	4.28	2.28	3.14	1.08	**20**
25					9.26	13.11	5.35	3.18	3.93	1.63	**25**
30					11.12	18.35	6.42	4.83	4.72	2.28	**30**
35					12.97	24.42	7.49	6.43	5.50	3.04	**35**
40							8.56	8.23	6.29	3.89	**40**
45							9.64	10.24	7.08	4.84	**45**
50							10.71	12.45	7.87	5.88	**50**
55							11.78	14.85	8.65	7.01	**55**
60							12.85	17.45	9.44	8.24	**60**
65									10.23	9.56	**65**
70									11.01	10.96	**70**
75									11.80	12.46	**75**
80									12.59	14.04	**80**
85									13.37	15.71	**85**
90									14.16	17.46	**90**
95											**95**
100											**100**
110											**110**
120											**120**
130											**130**
140											**140**
150											**150**
160											**160**
170											**170**
180											**180**
190											**190**
200											**200**
250											**250**
300											**300**
350											**350**
400											**400**
500											**500**
600											**600**

Table B-3 (Cont'd) Friction Loss Characteristics for PVC Schedule 40 Pipe

PVC SCHEDULE 40									
PVC SCHEDULE 40 IPS PLASTIC PIPE (1120, 1220); C = 150									
FRICTION LOSS CHARACTERISTICS									
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)									
I.D.	2.067in		2.469in		3.068in		4.026in		**I.D.**
Nominal	**2.00in**		**2.50in**		**3.00in**		**4.00in**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1									**1**
2									**2**
4	0.38	0.02							**4**
6	0.57	0.03							**6**
8	0.76	0.06	0.53	0.02					**8**
10	0.95	0.09	0.66	0.04	0.43	0.01			**10**
15	1.42	0.19	1.00	0.08	0.65	0.03			**15**
20	1.90	0.32	1.33	0.13	0.86	0.05			**20**
25	2.38	0.48	1.67	0.20	1.08	0.08	0.62	0.02	**25**
30	2.86	0.68	2.00	0.29	1.30	0.10	0.75	0.03	**30**
35	3.34	0.90	2.34	0.38	1.51	0.13	0.88	0.04	**35**
40	3.81	1.15	2.67	0.49	1.73	0.17	1.00	0.04	**40**
45	4.29	1.43	3.01	0.60	1.95	0.21	1.13	0.06	**45**
50	4.77	1.74	3.34	0.73	2.16	0.26	1.25	0.07	**50**
55	5.25	2.08	3.68	0.88	2.38	0.30	1.38	0.08	**55**
60	5.72	2.44	4.01	1.03	2.60	0.36	1.51	0.10	**60**
65	6.20	2.83	4.35	1.19	2.81	0.41	1.63	0.11	**65**
70	6.68	3.25	4.68	1.37	3.03	0.48	1.76	0.13	**70**
75	7.16	3.69	5.01	1.56	3.25	0.54	1.88	0.14	**75**
80	7.63	4.16	5.35	1.75	3.46	0.61	2.01	0.16	**80**
85	8.11	4.66	5.68	1.96	3.68	0.68	2.13	0.18	**85**
90	8.59	5.18	6.02	2.18	3.90	0.76	2.26	0.20	**90**
95	9.07	5.72	6.35	2.41	4.11	0.84	2.39	0.22	**95**
100	9.54	6.29	6.69	2.65	4.33	0.92	2.51	0.25	**100**
110	10.50	7.51	7.36	3.16	4.76	1.10	2.76	0.29	**110**
120	11.45	8.82	8.03	3.72	5.20	1.29	3.02	0.34	**120**
130	12.41	10.23	8.70	4.31	5.63	1.50	3.27	0.40	**130**
140	13.36	11.74	9.37	4.94	6.06	1.72	3.52	0.46	**140**
150	14.32	13.33	10.03	5.62	6.50	1.95	3.77	0.52	**150**
160	15.27	15.03	10.70	6.33	6.93	2.20	4.02	0.59	**160**
170	16.23	16.81	11.37	7.08	7.36	2.46	4.27	0.66	**170**
180			12.04	7.87	7.80	2.74	4.53	0.73	**180**
190			12.71	8.70	8.23	3.02	4.78	0.81	**190**
200			13.38	9.57	8.66	3.33	5.03	0.89	**200**
250			16.73	14.47	10.83	5.03	6.29	1.34	**250**
300					13.00	7.05	7.55	1.88	**300**
350					15.17	9.38	8.81	2.50	**350**
400					17.33	12.01	10.06	3.20	**400**
500					19.50	14.93	12.58	4.84	**500**
600							15.10	6.78	**600**

Table B-4 Friction Loss Characteristics for Aluminum Pipe with Couplers

ALUMINUM PIPE WITH COUPLERS															
ALUMINUM PIPE WITH COUPLERS; C = 130															
FRICTION LOSS CHARACTERISTICS															
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)															
I.D.	2.000in		3.000in		4.000in		5.000in		6.000in		7.000in		8.000in		**I.D.**
Nominal	**2.00in**		**3.00in**		**4.00in**		**5.00in**		**6.00in**		**7.00in**		**8.00in**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1	0.10	0.00													**1**
2	0.20	0.01													**2**
4	0.41	0.03	0.18	0.00											**4**
6	0.61	0.06	0.27	0.01											**6**
8	0.82	0.10	0.36	0.01											**8**
10	1.02	0.15	0.45	0.02	0.26	0.00									**10**
15	1.53	0.32	0.68	0.04	0.38	0.01	0.25	0.00							**15**
20	2.04	0.55	0.91	0.07	0.51	0.02	0.33	0.01							**20**
25	2.55	0.83	1.13	0.11	0.64	0.03	0.41	0.01	0.28	0.00					**25**
30	3.06	1.16	1.36	0.15	0.77	0.04	0.49	0.01	0.34	0.01					**30**
35	3.57	1.55	1.59	0.20	0.89	0.05	0.57	0.02	0.40	0.01					**35**
40	4.08	1.98	1.82	0.25	1.02	0.06	0.65	0.02	0.45	0.01					**40**
45	4.60	2.47	2.04	0.31	1.15	0.08	0.74	0.03	0.51	0.01					**45**
50	5.11	3.00	2.27	0.38	1.28	0.09	0.82	0.03	0.57	0.01					**50**
55	5.62	3.57	2.50	0.46	1.40	0.11	0.90	0.04	0.62	0.02					**55**
60	6.13	4.20	2.72	0.54	1.53	0.13	0.98	0.04	0.68	0.02					**60**
65	6.64	4.87	2.95	0.62	1.66	0.15	1.06	0.05	0.74	0.02					**65**
70	7.15	5.58	3.18	0.71	1.79	0.18	1.14	0.06	0.79	0.02	0.58	0.01			**70**
75	7.66	6.34	3.40	0.81	1.91	0.20	1.23	0.07	0.85	0.03	0.63	0.01			**75**
80	8.17	7.15	3.63	0.91	2.04	0.22	1.31	0.08	0.91	0.03	0.67	0.01			**80**
85	8.68	8.00	3.86	1.02	2.17	0.25	1.39	0.08	0.96	0.03	0.71	0.02			**85**
90	9.19	8.89	4.08	1.13	2.30	0.28	1.47	0.09	1.02	0.04	0.75	0.02			**90**
95	9.70	9.82	4.31	1.25	2.43	0.31	1.55	0.10	1.08	0.04	0.79	0.02			**95**
100	10.21	10.80	4.54	1.38	2.55	0.34	1.63	0.11	1.13	0.05	0.83	0.02			**100**
110	11.23	12.88	4.99	1.64	2.81	0.41	1.80	0.14	1.25	0.06	0.92	0.03	0.70	0.01	**110**
120	12.25	15.13	5.45	1.93	3.06	0.48	1.96	0.16	1.36	0.07	1.00	0.03	0.77	0.02	**120**
130	13.28	17.55	5.90	2.24	3.32	0.55	2.12	0.19	1.48	0.08	1.08	0.04	0.83	0.02	**130**
140			6.35	2.57	3.57	0.63	2.29	0.21	1.59	0.09	1.17	0.04	0.89	0.02	**140**
150			6.81	2.92	3.83	0.72	2.45	0.24	1.70	0.10	1.25	0.05	0.96	0.02	**150**
160			7.26	3.29	4.08	0.81	2.61	0.27	1.82	0.11	1.33	0.05	1.02	0.03	**160**
170			7.72	3.68	4.34	0.91	2.78	0.31	1.93	0.13	1.42	0.06	1.09	0.03	**170**
180			8.17	4.09	4.60	1.01	2.94	0.34	2.04	0.14	1.50	0.07	1.15	0.03	**180**
190			8.62	4.52	4.85	1.11	3.10	0.38	2.16	0.15	1.58	0.07	1.21	0.04	**190**
200			9.08	4.97	5.11	1.22	3.27	0.41	2.27	0.17	1.67	0.08	1.28	0.04	**200**
250			11.35	7.51	6.38	1.85	4.08	0.62	2.84	0.26	2.08	0.12	1.60	0.06	**250**
300			13.62	10.52	7.66	2.59	4.90	0.87	3.40	0.36	2.50	0.17	1.91	0.09	**300**
350			15.89	14.00	8.94	3.45	5.72	1.16	3.97	0.48	2.92	0.23	2.23	0.12	**350**
400			18.15	17.92	10.21	4.41	6.54	1.49	4.54	0.61	3.33	0.29	2.55	0.15	**400**
500					12.76	6.67	8.17	2.25	5.67	0.93	4.17	0.44	3.19	0.23	**500**
600					15.32	9.35	9.80	3.15	6.81	1.30	5.00	0.61	3.83	0.32	**600**
700							11.42	4.19	7.93	1.70	5.83	0.79	4.46	0.42	**700**

Table B-5 Friction Loss Characteristics for Schedule 40 Standard Steel Pipe

SCHEDULE 40 STANDARD STEEL PIPE											
SCHEDULE 40 STANDARD STEEL PIPE; C = 100											
FRICTION LOSS CHARACTERISTICS											
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)											
I.D.	0.622		0.824in		1.049in		1.380in		1.610in		**I.D.**
Nominal	**0.50in**		**0.75in**		**1.00in**		**1.25in**		**1.50in**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1	1.05	0.91	0.60	0.23	0.37	0.07	0.21	0.02	0.15	0.01	**1**
2	2.10	3.28	1.20	0.84	0.74	0.26	0.42	0.07	0.31	0.03	**2**
4	4.21	11.85	2.40	3.02	1.48	0.93	0.85	0.25	0.62	0.12	**4**
6	6.32	25.10	3.60	6.39	2.22	1.97	1.28	0.52	0.94	0.25	**6**
8	8.43	42.77	4.80	10.89	2.96	3.36	1.71	0.89	1.25	0.42	**8**
10	10.54	64.65	6.00	16.46	3.70	5.08	2.14	1.34	1.57	0.63	**10**
15			9.01	35.00	5.56	10.81	3.21	2.85	2.35	1.35	**15**
20			12.01	59.41	7.41	18.35	4.28	4.83	3.14	2.28	**20**
25			15.02	89.92	9.26	27.78	5.36	7.32	3.93	3.45	**25**
30					11.12	38.89	6.42	10.24	4.72	4.84	**30**
35					12.97	51.74	7.49	13.62	5.50	6.44	**35**
40					14.83	66.25	8.56	17.45	6.29	8.24	**40**
45					16.68	82.40	9.64	21.70	7.08	10.25	**45**
50							10.71	26.37	7.87	12.46	**50**
55							11.78	31.47	8.65	14.86	**55**
60							12.85	36.97	9.44	17.46	**60**
65							13.92	42.88	10.23	20.25	**65**
70							14.99	49.18	11.01	23.23	**70**
75							16.06	55.89	11.80	26.40	**75**
80							17.13	62.98	12.59	29.75	**80**
85							18.21	70.47	13.37	33.29	**85**
90							19.28	78.33	14.16	37.00	**90**
95									14.95	40.90	**95**
100									15.74	44.97	**100**
110									17.31	53.66	**110**
120									18.88	63.04	**120**
130											**130**
140											**140**
150											**150**
160											**160**
170											**170**
180											**180**
190											**190**
200											**200**
250											**250**
300											**300**
350											**350**
400											**400**
500											**500**
600											**600**

Table B-5 (Cont'd) Friction Loss Characteristics for Schedule 40 Standard Steel Pipe

SCHEDULE 40 STANDARD STEEL PIPE									
SCHEDULE 40 STANDARD STEEL PIPE; C = 100									
FRICTION LOSS CHARACTERISTICS									
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)									
I.D.	2.067in		2.469in		3.068in		3.548in		**I.D.**
Nominal	**2.00in**		**2.50in**		**3.00in**		**3.50in**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1	0.09	0.00							**1**
2	0.19	0.01	0.13	0.00					**2**
4	0.38	0.03	0.26	0.01	0.17	0.00			**4**
6	0.57	0.07	0.40	0.03	0.26	0.01	0.19	0.00	**6**
8	0.76	0.12	0.53	0.05	0.34	0.02	0.25	0.01	**8**
10	0.95	0.19	0.66	0.08	0.43	0.03	0.32	0.01	**10**
15	1.43	0.40	1.00	0.17	0.65	0.06	0.48	0.03	**15**
20	1.90	0.68	1.33	0.29	0.86	0.10	0.64	0.05	**20**
25	2.39	1.03	1.67	0.43	1.08	0.15	0.80	0.07	**25**
30	2.86	1.43	2.00	0.60	1.30	0.21	0.97	0.10	**30**
35	3.34	1.91	2.34	0.80	1.51	0.28	1.13	0.14	**35**
40	3.81	2.44	2.67	1.03	1.73	0.36	1.29	0.18	**40**
45	4.29	3.04	3.01	1.28	1.95	0.44	1.45	0.22	**45**
50	4.77	3.69	3.34	1.56	2.16	0.54	1.62	0.27	**50**
55	5.25	4.41	3.68	1.86	2.38	0.65	1.78	0.32	**55**
60	5.72	5.18	4.01	2.18	2.60	0.76	1.94	0.37	**60**
65	6.20	6.00	4.35	2.53	2.81	0.88	2.10	0.43	**65**
70	6.68	6.89	4.68	2.90	3.03	1.01	2.26	0.50	**70**
75	7.16	7.83	5.01	3.30	3.25	1.15	2.43	0.56	**75**
80	7.63	8.82	5.35	3.72	3.46	1.29	2.59	0.64	**80**
85	8.11	9.87	5.68	4.16	3.68	1.44	2.75	0.71	**85**
90	8.59	10.97	6.02	4.62	3.90	1.61	2.91	0.79	**90**
95	9.07	12.13	6.35	5.11	4.11	1.78	3.07	0.88	**95**
100	9.54	13.33	6.69	5.62	4.33	1.95	3.24	0.96	**100**
110	10.50	15.91	7.36	6.70	4.76	2.33	3.56	1.15	**110**
120	11.45	18.69	8.03	7.87	5.20	2.74	3.88	1.35	**120**
130	12.41	21.68	8.70	9.13	5.63	3.17	4.21	1.56	**130**
140	13.36	24.87	9.37	10.47	6.06	3.64	4.53	1.79	**140**
150	14.32	28.26	10.03	11.90	6.50	4.14	4.86	2.04	**150**
160	15.27	31.84	10.70	13.41	6.93	4.66	5.18	2.30	**160**
170	16.23	35.63	11.37	15.01	7.36	5.22	5.50	2.57	**170**
180	17.18	39.61	12.04	16.68	7.80	5.80	5.83	2.86	**180**
190	18.14	43.78	12.71	18.44	8.23	6.41	6.15	3.16	**190**
200	19.09	48.14	13.38	20.28	8.66	7.05	6.48	3.47	**200**
250			16.73	30.65	10.83	10.65	8.10	5.25	**250**
300					13.00	14.93	9.72	7.36	**300**
350					15.17	19.87	11.34	9.79	**350**
400					17.33	25.44	12.96	12.54	**400**
500							16.20	18.96	**500**
600							19.44	26.57	**600**

Table B-6 Friction Loss Characteristics for Polyethylene (PE) Pipe

PE SDR-PRESSURE RATED TUBING										
PE SDR-PRESSURE RATED TUBING (2306, 3206, 3306) SDR 7, 9, 11.5; C = 140										
FRICTION LOSS CHARACTERISTICS										
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)										
I.D.	2.067in		2.469in		3.068in		4.026in		**I.D.**
Nominal	**2.00in**		**2.50in**		**3.00in**		**4.00in**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1	0.09	0.00							**1**
2	0.19	0.01							**2**
4	0.38	0.02	0.26	0.01					**4**
6	0.57	0.04	0.40	0.02	0.26	0.01			**6**
8	0.76	0.07	0.53	0.03	0.34	0.01			**8**
10	0.95	0.10	0.66	0.04	0.43	0.01			**10**
15	1.42	0.21	1.00	0.09	0.64	0.04	0.37	0.01	**15**
20	1.90	0.36	1.33	0.15	0.86	0.05	0.50	0.01	**20**
25	2.39	0.55	1.67	0.23	1.08	0.08	0.62	0.02	**25**
30	2.86	0.77	2.00	0.32	1.30	0.11	0.75	0.03	**30**
35	3.34	1.02	2.34	0.43	1.51	0.15	0.88	0.04	**35**
40	3.81	1.31	2.67	0.55	1.73	0.19	1.00	0.05	**40**
45	4.29	1.63	3.01	0.69	1.95	0.24	1.13	0.06	**45**
50	4.77	1.98	3.34	0.83	2.16	0.29	1.25	0.08	**50**
55	5.25	2.36	3.68	1.00	2.38	0.35	1.38	0.09	**55**
60	5.72	2.78	4.01	1.17	2.60	0.41	1.51	0.11	**60**
65	6.20	3.22	4.35	1.36	2.81	0.47	1.63	0.13	**65**
70	6.68	3.69	4.68	1.56	3.03	0.54	1.76	0.14	**70**
75	7.16	4.20	5.01	1.77	3.25	0.61	1.88	0.16	**75**
80	7.63	4.73	5.35	1.99	3.46	0.69	2.01	0.18	**80**
85	8.11	5.29	5.68	2.23	3.68	0.77	2.13	0.21	**85**
90	8.59	5.88	6.02	2.48	3.90	0.86	2.26	0.23	**90**
95	9.07	6.50	6.35	2.74	4.11	0.96	2.39	0.25	**95**
100	9.54	7.15	6.69	3.01	4.33	1.05	2.51	0.28	**100**
110	10.50	8.53	7.36	3.59	4.76	1.25	2.76	0.33	**110**
120	11.45	10.02	8.03	4.22	5.20	1.47	3.02	0.39	**120**
130	12.41	11.62	8.70	4.90	5.63	1.70	3.27	0.45	**130**
140	13.36	13.33	9.37	5.62	6.06	1.95	3.52	0.52	**140**
150	14.32	15.15	10.03	6.38	6.50	2.22	3.77	0.59	**150**
160	15.27	17.08	10.70	7.19	6.93	2.50	4.02	0.67	**160**
170	16.23	19.11	11.37	8.05	7.36	2.80	4.27	0.75	**170**
180	17.18	21.24	12.04	8.95	7.08	3.11	4.53	0.83	**180**
190	18.14	23.48	12.71	9.89	8.23	3.44	4.78	0.92	**190**
200	19.09	25.81	13.38	10.87	8.66	3.78	5.03	1.01	**200**
250			16.73	16.44	10.83	5.71	6.29	1.52	**250**
300					13.00	8.01	7.55	2.13	**300**
350					15.17	10.65	8.81	2.84	**350**
400					17.33	13.64	10.06	3.64	**400**
500							12.58	5.50	**500**
600							15.10	7.70	**600**

Table B-7 Friction Loss Characteristics for Asbestos-Cement Pipe

ASBESTOS-CEMENT PIPE											
ASBESTOS-CEMENT PIPE; C = 140											
FRICTION LOSS CHARACTERISTICS											
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)											
I.D.											**I.D.**
Nominal	**3.00in**		**3.50in**		**4.00in**		**4.50in**		**5.00in**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1											**1**
2											**2**
4											**4**
6											**6**
8	0.36	0.01									**8**
10	0.45	0.02	0.33	0.01							**10**
15	0.68	0.03	0.50	0.02	0.38	0.01					**15**
20	0.91	0.06	0.67	0.03	0.51	0.02					**20**
25	1.13	0.09	0.83	0.04	0.64	0.02	0.50	0.01			**25**
30	1.36	0.13	1.00	0.06	0.77	0.03	0.61	0.02			**30**
35	1.59	0.17	1.17	0.08	0.89	0.04	0.71	0.02	0.57	0.01	**35**
40	1.82	0.21	1.33	0.10	1.02	0.05	0.81	0.03	0.65	0.02	**40**
45	2.04	0.27	1.50	0.13	1.15	0.07	0.91	0.04	0.74	0.02	**45**
50	2.27	0.32	1.67	0.16	1.28	0.08	1.01	0.05	0.82	0.03	**50**
55	2.50	0.39	1.83	0.19	1.40	0.10	1.11	0.06	0.90	0.03	**55**
60	2.72	0.45	2.00	0.22	1.53	0.12	1.21	0.06	0.98	0.04	**60**
65	2.95	0.53	2.17	0.26	1.66	0.13	1.31	0.08	1.06	0.05	**65**
70	3.18	0.60	2.33	0.29	1.79	0.15	1.41	0.09	1.14	0.05	**70**
75	3.40	0.69	2.50	0.33	1.91	0.17	1.51	0.10	1.23	0.06	**75**
80	3.63	0.77	2.67	0.38	2.04	0.20	1.61	0.11	1.31	0.07	**80**
85	3.86	0.86	2.83	0.42	2.17	0.22	1.71	0.12	1.39	0.07	**85**
90	4.08	0.96	3.00	0.47	2.30	0.24	1.82	0.14	1.47	0.08	**90**
95	4.31	1.06	3.17	0.52	2.43	0.27	1.92	0.15	1.55	0.09	**95**
100	4.54	1.17	3.33	0.57	2.55	0.30	2.02	0.17	1.63	0.10	**100**
110	4.99	1.39	3.67	0.68	2.81	0.35	2.22	0.20	1.80	0.12	**110**
120	5.45	1.64	4.00	0.80	3.06	0.41	2.42	0.23	1.96	0.14	**120**
130	5.90	1.90	4.33	0.92	3.32	0.48	2.62	0.27	2.12	0.16	**130**
140	6.35	2.18	4.67	1.06	3.57	0.55	2.82	0.31	2.29	0.19	**140**
150	6.81	2.47	5.00	1.20	3.83	0.63	3.03	0.35	2.45	0.21	**150**
200	9.08	4.21	6.67	2.05	5.11	1.07	4.03	0.60	3.27	0.36	**200**
250	11.35	6.36	8.34	3.09	6.38	1.61	5.04	0.91	4.08	0.54	**250**
300	13.62	8.91	10.00	4.33	7.66	2.26	6.05	1.27	4.90	0.76	**300**
350	15.89	11.85	11.67	5.76	8.94	3.01	7.06	1.69	5.72	1.01	**350**
400	18.15	15.17	13.34	7.38	10.21	3.85	8.07	2.17	6.54	1.30	**400**
500			16.67	11.14	12.76	5.82	10.09	3.28	8.17	1.96	**500**
600			20.01	15.62	15.32	8.15	12.10	4.59	9.80	2.75	**600**
800					20.42	13.88	16.14	7.82	13.07	4.68	**800**
1000							20.17	11.82	16.34	7.07	**1000**
1500											**1500**
2000											**2000**

Table B-7 (Cont'd) Friction Loss Characteristics for Asbestos-Cement Pipe

ASBESTOS-CEMENT PIPE									
ASBESTOS-CEMENT PIPE; C = 140									
FRICTION LOSS CHARACTERISTICS									
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)									
I.D.									**I.D.**
Nominal	**6.00in**		**7.00in**		**8.00in**		**10.00in**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1									**1**
2									**2**
4									**4**
6									**6**
8									**8**
10									**10**
15									**15**
20									**20**
25									**25**
30									**30**
35									**35**
40									**40**
45									**45**
50									**50**
55	0.62	0.01							**55**
60	0.68	0.02							**60**
65	0.74	0.02							**65**
70	0.79	0.02							**70**
75	0.85	0.02							**75**
80	0.91	0.03							**80**
85	0.96	0.03	0.71	0.01					**85**
90	1.02	0.03	0.75	0.02					**90**
95	1.08	0.04	0.79	0.02					**95**
100	1.13	0.04	0.83	0.02					**100**
110	1.25	0.05	0.92	0.02					**110**
120	1.36	0.06	1.00	0.03	0.77	0.01			**120**
130	1.48	0.07	1.08	0.03	0.83	0.02			**130**
140	1.59	0.08	1.17	0.04	0.89	0.02			**140**
150	1.70	0.09	1.25	0.04	0.96	0.02			**150**
200	2.27	0.15	1.67	0.07	1.28	0.04	0.82	0.01	**200**
250	2.84	0.22	2.08	0.11	1.60	0.06	1.02	0.02	**250**
300	3.40	0.31	2.50	0.15	1.91	0.08	1.23	0.03	**300**
350	3.97	0.42	2.92	0.20	2.23	0.10	1.43	0.03	**350**
400	4.54	0.53	3.33	0.25	2.55	0.13	1.63	0.04	**400**
500	5.67	0.81	4.17	0.38	3.19	0.20	2.04	0.07	**500**
600	6.81	1.13	5.00	0.53	3.83	0.28	2.45	0.09	**600**
800	9.08	1.93	6.67	0.91	5.11	0.47	3.27	0.16	**800**
1000	11.35	2.91	8.34	1.37	6.38	0.72	4.08	0.24	**1000**
1500	17.02	6.16	12.50	2.91	9.57	1.52	6.13	0.51	**1500**
2000			16.67	4.95	12.76	2.58	8.17	0.87	**2000**

Table B-8 Friction Loss Characteristics for Small Diameter PE Hose & Lay Flat Hose

SMALL DIAMETER PE & LAY FLAT HOSE													
FRICTION LOSS CHARACTERISTICS													
Fc = psi loss per 100 feet of pipe (**psi/100ft**); Velocity = feet per second (**Fps**)													
I.D.	1.00in		1.50in		2.00in		3.00in		4.00in		6.00in		**I.D.**
Nominal	**1.00in**		**1.50in**		**2.00in**		**3.00in**		**4.00in**		**6.00in**		**Nominal**
Flow	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	Vel.	Fc	**Flow**
Gpm	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	Fps	Psi	**Gpm**
1	0.38	0.04	0.16	0.01	0.10	0.00							**1**
2	0.76	0.14	0.32	0.02	0.19	0.01							**2**
4	1.51	0.52	0.65	0.07	0.39	0.02							**4**
6	2.27	1.10	0.97	0.14	0.58	0.04							**6**
8	3.02	1.87	1.29	0.24	0.78	0.07							**8**
10	3.78	2.83	1.62	0.36	0.97	0.10							**10**
14	5.29	5.29	2.26	0.67	1.36	0.20	0.36	0.01	0.36	0.01			**14**
18	6.80	8.42	2.91	1.06	1.75	0.31	0.46	0.01	0.46	0.01			**18**
20	7.55	10.23	3.23	1.29	1.95	0.38	0.51	0.01	0.51	0.01			**20**
25	9.44	15.47	4.04	1.96	2.44	0.57	0.64	0.02	0.64	0.02			**25**
30	11.33	21.68	4.85	2.74	2.92	0.80	0.77	0.03	0.77	0.03			**30**
35	13.22	28.84	5.66	3.65	3.41	1.07	0.90	0.04	0.90	0.04			**35**
40	15.11	36.94	6.46	4.67	3.90	1.37	1.03	0.05	1.03	0.05			**40**
45	17.00	45.94	7.27	5.81	4.39	1.70	1.99	0.25	1.15	0.07			**45**
50			8.08	7.06	4.87	2.06	2.21	0.30	1.28	0.08	0.58	0.01	**50**
55			8.89	8.43	5.36	2.46	2.43	0.36	1.41	0.10	0.63	0.01	**55**
60			9.70	9.90	5.85	2.89	2.66	0.42	1.54	0.11	0.69	0.02	**60**
65			10.50	11.48	6.34	3.36	2.88	0.49	1.67	0.13	0.75	0.02	**65**
70			11.31	13.17	6.82	3.85	3.10	0.56	1.80	0.15	0.81	0.02	**70**
75			12.12	14.97	7.31	4.37	3.32	0.64	1.92	0.17	0.87	0.02	**75**
80			12.93	16.87	7.80	4.93	3.54	0.72	2.05	0.19	0.92	0.03	**80**
85			13.73	18.87	8.29	5.51	3.76	0.81	2.18	0.21	0.98	0.03	**85**
90			14.54	20.98	8.77	6.13	3.98	0.90	2.31	0.24	1.04	0.03	**90**
100					9.75	7.45	4.43	1.09	2.56	0.29	1.15	0.04	**100**
110					10.72	8.89	4.87	1.30	2.82	0.34	1.27	0.05	**110**
120					11.70	10.44	5.31	1.53	3.08	0.40	1.38	0.06	**120**
130					12.67	12.11	5.75	1.77	3.33	0.47	1.50	0.07	**130**
140					13.65	13.90	6.20	2.03	3.59	0.54	1.62	0.08	**140**
150					14.62	15.79	6.64	2.31	3.85	0.61	1.73	0.09	**150**
160							7.08	2.60	4.10	0.69	1.85	0.10	**160**
170							7.52	2.91	4.36	0.77	1.96	0.11	**170**
180							7.97	3.24	4.62	0.86	2.08	0.12	**180**
190							8.41	3.58	4.87	0.95	2.19	0.14	**190**
200							8.85	3.93	5.13	1.04	2.31	0.15	**200**
250							11.07	5.95	6.41	1.57	2.88	0.23	**250**
300							13.28	8.33	7.69	2.21	3.46	0.32	**300**
350							15.49	11.09	8.89	2.94	4.04	0.42	**350**
400									10.26	3.76	4.62	0.54	**400**
500									12.82	5.68	5.77	0.81	**500**
600									15.39	7.97	6.92	1.14	**600**
700											8.08	1.52	**700**
800											9.23	1.94	**800**
900											10.38	2.41	**900**
1000											11.54	2.93	**1000**
1200											13.85	4.11	**1200**
1400											16.15	5.47	**1400**
1600											18.46	7.01	**1600**
1800											20.77	8.71	**1800**
2000											23.08	10.59	**2000**

APPENDIX C
SPRINKLER PERFORMANCE DATA

Every company that manufactures and sells sprinklers evaluates and publishes the data about how each sprinkler will perform. Typically, these sprinkler performance data include the nozzle diameter, the pressure the sprinkler is expected to operate at, and the discharge and wetted diameter the sprinkler will produce at each pressure.

In the interest of simplicity of use of this Irrigation Guide and the example problems, the authors have selected nine generic sprinkler models and have presented the performance data for each of these nine sprinkler models. The nine sprinkler models range in size from very small sprinklers with nozzles sizes as small as one sixteenth of an inch to very large sprinklers with nozzles as large as 1.45 inches. The shaded areas are not recommended for design use. These data are presented below.

Table C-A Sprinkler Performance Data for Sprinkler A

	Nozzle 1/16”		Nozzle 5/64”		Nozzle 3/32”		Nozzle 7/64”	
psi	Gpm	Dia.	Gpm	Dia.	Gpm	Dia.	Gpm	Dia.
20	0.50	57	0.78	61	1.14	66	1.55	68
25	0.56	58	0.88	62	1.27	67	1.73	70
30	0.62	59	0.97	63	1.40	68	1.89	71
35	0.67	60	1.05	64	1.51	69	2.05	72
40	0.72	61	1.12	65	1.62	70	2.20	74
45	0.76	62	1.19	66	1.72	71	2.32	75
50	0.80	63	1.25	67	1.80	72	2.44	76
55	0.85	64	1.29	68	1.88	73	2.56	77
60	0.88	65	1.34	69	1.98	74	2.69	77

Table C-B Sprinkler Performance Data for Sprinkler B

	Nozzle 1/8”		Nozzle 9/64”		Nozzle 5/32”		Nozzle 11/64”		Nozzle 3/16”	
psi	Gpm	Dia.	Gpm	Dia.	Gpm	Dia.	Gpm	Dia.	Gpm	Dia.
25	2.44	70	2.91	75	3.52	75	4.35	76	5.00	78
30	2.66	73	3.22	76	3.92	76	4.72	77	5.52	80
35	2.86	76	3.56	77	4.25	78	5.13	79	6.02	82
40	3.04	78	3.73	78	4.51	79	5.44	80	6.43	83
45	3.22	79	3.92	79	4.68	80	5.68	81	6.85	84
50	3.39	80	4.15	80	5.16	81	6.10	82	7.18	85
55	3.55	81	4.36	81	5.32	82	6.25	83	7.49	86
60	3.70	82	4.58	82	5.59	83	6.53	84	7.78	87

Table C-C Sprinkler Performance Data for Sprinkler C

	Nozzle 9/64”		Nozzle 5/32”		Nozzle 11/64”		Nozzle 3/16”		Nozzle 13/64”		Nozzle 7/32”	
psi	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**
25	2.90	80	3.32	82	4.24	83	5.00	85	5.89	85	6.83	88
30	3.16	81	3.85	85	4.64	88	5.50	91	6.51	94	7.58	96
35	3.40	82	4.16	87	5.02	90	5.97	94	7.08	97	8.26	100
40	3.63	83	4.45	88	5.37	92	6.41	96	7.60	99	8.87	102
45	3.84	84	4.72	89	5.70	93	6.81	98	8.07	101	9.41	104
50	4.04	85	4.98	90	6.01	95	7.18	100	8.49	103	9.58	106
55	4.22	86	5.22	91	6.30	96	7.51	101	8.87	104	10.30	107
60	4.38	87	5.44	92	6.56	97	7.82	102	9.20	105	10.60	108
65	4.65	88	5.73	93	6.83	98	8.19	103	9.47	106	10.95	109
70	4.80	89	5.93	94	7.08	99	8.48	104	9.78	107	11.29	110
75	5.00	90	6.16	95	7.34	100	8.78	105	10.18	108	11.71	111
80	5.18	91	6.32	96	7.58	101	9.09	106	10.52	109	--	--

Table C-D Sprinkler Performance Data for Sprinkler D

	Nozzles 5/32” x 3/32”		Nozzles 11/64” x3/32”		Nozzles 3/16”x1/8”		Nozzles 13/64”x1/8”		Nozzles 7/32”x1/8”	
psi	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**
25	4.83	92	5.50	97	7.41	98	8.30	101	9.24	102
30	5.26	95	6.07	98	8.14	100	9.15	103	10.20	105
35	5.71	97	6.57	101	8.83	102	9.94	105	11.10	108
40	6.11	98	7.03	103	9.48	104	10.70	107	11.90	111
45	6.48	100	7.46	104	10.10	106	11.30	108	12.70	114
50	6.84	101	7.87	105	10.60	107	11.90	111	13.30	117
55	7.17	102	8.25	106	11.10	108	12.50	113	13.90	119
60	7.47	103	8.59	107	11.60	109	13.00	114	14.40	121
65	7.77	104	8.91	108	12.00	110	13.50	115	14.90	122
70	8.07	105	9.23	109	12.40	111	14.00	116	15.40	123
75	8.37	106	9.55	110	12.80	112	14.50	117	15.90	124
80	8.67	107	9.87	111	13.20	113	15.00	118	16.40	125

Table C-E Sprinkler Performance Data for Sprinkler E

	Nozzle 7/32”		Nozzle 1/4”		Nozzle 9/32”		Nozzle 5/16”		Nozzle 11/32”		Nozzle 3/8”	
psi	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**
40	8.8	121	11.5	128	14.6	130	17.7	132	21.1	136	24.4	145
45	9.4	123	12.2	131	15.5	134	18.9	136	22.5	142	25.0	151
50	9.9	125	12.9	134	16.3	138	20.0	140	23.8	148	27.5	157
55	10.4	127	13.6	136	17.2	141	21.0	144	25.0	152	29.1	161
60	10.9	129	14.2	139	18.0	144	22.0	148	26.2	156	30.8	165
65	11.4	131	14.8	142	18.8	147	23.0	152	27.4	160	32.0	167
70	11.8	134	15.4	145	19.5	150	23.9	155	28.5	164	33.2	173
75	12.2	137	16.0	148	20.3	153	24.8	158	29.6	168	34.5	177
80	12.6	140	16.5	151	20.9	156	25.7	161	30.6	172	35.7	181

Table C-F Sprinkler Performance Data for Sprinkler F

	Nozzles 7/32” x 3/16”		Nozzles 1/4”x 3/16”		Nozzles 1/4”x7/32”		Nozzles 5/16”x7/32”		Nozzles 3/8”x 1/4”	
psi	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**
35	14.4	115	16.6	117	18.8	117	23.8	125	32.1	128
40	15.4	116	17.8	120	20.1	120	25.5	128	34.3	131
45	16.4	117	18.9	122	21.3	122	27.2	130	36.5	134
50	17.2	119	20.1	123	22.5	123	28.8	132	38.5	137
55	18.0	120	21.2	125	23.6	125	30.3	134	40.5	140
60	18.8	121	22.2	126	24.7	126	31.8	136	42.3	143
65	19.7	123	23.0	128	25.8	128	33.2	139	44.0	146
70	20.5	126	23.8	130	26.8	130	34.6	142	45.9	149
75	21.2	129	24.6	132	27.8	132	35.9	145	47.6	152
80	22.0	132	25.4	133	28.8	133	37.1	147	49.1	155

Table C-G Sprinkler Performance Data for Sprinkler **G**

	Nozzles 11/32”x7/32”		Nozzles 3/8”x 7/32”		Nozzles 13/32”x7/32”		Nozzles 7/16”x1/4”		Nozzles 15/32”x1/4”		Nozzles 17/32”x1/4”		Nozzles 5/8”x1/4”	
psi	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**
60	36.5	166	41.4	168	46.6	174	56.6	179	61.4	184	72.5	196	94.7	210
65	38.0	169	43.2	172	48.6	177	58.0	182	64.0	187	75.8	199	99.2	213
70	40.1	172	44.9	175	50.4	180	60.3	185	66.3	190	78.6	202	103.2	216
75	41.0	175	46.7	178	52.4	183	62.7	188	69.1	193	81.6	205	106.6	218
80	42.6	176	48.3	181	54.3	186	64.8	191	71.3	196	84.5	208	110.8	222
85	43.8	181	49.8	184	56.0	189	67.0	194	73.7	199	86.7	211	114.3	225
90	45.7	184	51.4	187	57.9	192	69.9	197	75.9	202	90.0	214	117.3	228
95	46.8	186	53.0	189	59.6	194	71.0	199	76.2	204	92.5	216	121.0	230
100	47.9	188	54.5	191	61.2	196	73.0	201	80.3	206	94.6	218	124.3	232

Table C-H Sprinkler Performance Data for Sprinkler H

	Nozzles 1/2" x 5/16" x 3/16"		Nozzles 9/16" x 5/16" x 3/16"		Nozzles 5/8" x 5/16" x 3/16"		Nozzles 11/16" x 5/16" x 3/16"		Nozzles 3/4" x 3/8" x 3/16"		Nozzles 13/16" x 3/8" x 3/16"		Nozzles 15/16" x 3/8" x 3/16"	
psi	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**
60	87	200	103	210	119	220	138	230	167	240	190	250	240	270
70	93	210	110	220	128	230	148	240	181	250	206	260	252	275
80	100	220	117	230	136	240	158	250	192	260	219	270	275	280
90	107	230	125	240	145	250	168	260	205	270	232	280	291	285
100	112	240	132	250	153	260	177	270	216	280	244	285	308	290
110	117	250	138	260	160	270	185	280	226	285	256	290	322	295

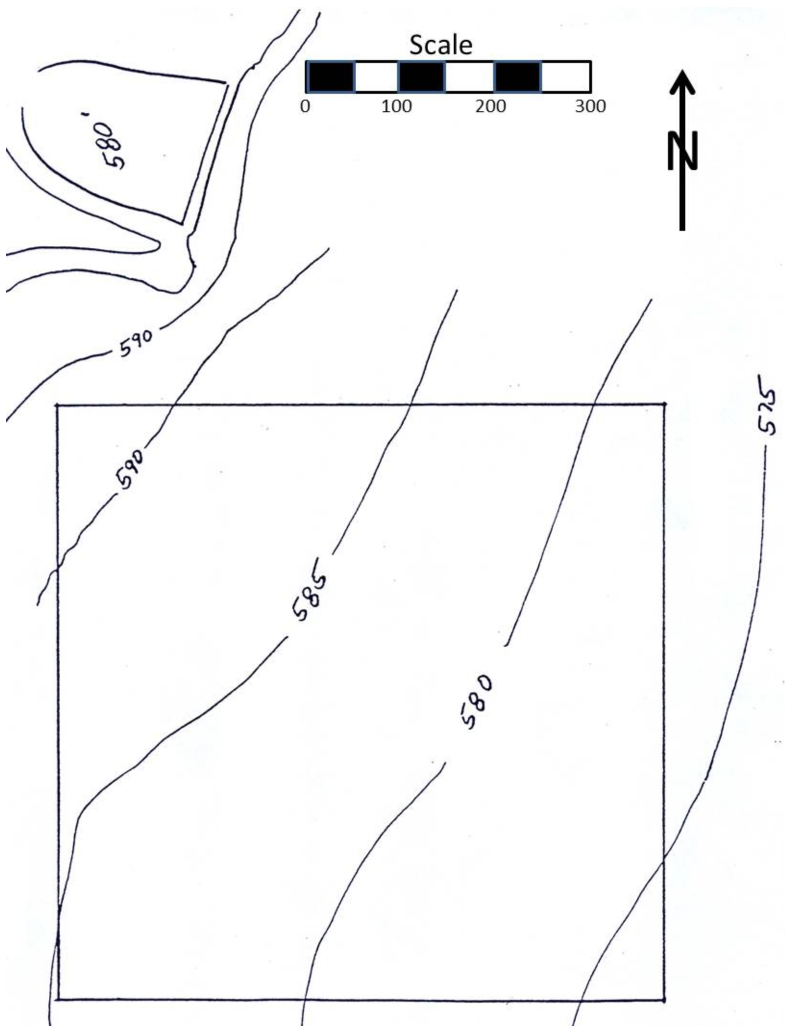
Table C-I Sprinkler Performance Data for Sprinkler I

	Nozzle 0.870"		Nozzle 0.990"		Nozzle 1.100"		Nozzle 1.201"		Nozzle 1.293"		Nozzle 1.380"		Nozzle 1.450"	
psi	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**	**Gpm**	**Dia.**
60	110	264	142	284	185	300	226	318	275	335	324	352	385	365
70	118	275	154	295	200	314	243	332	295	350	353	367	418	383
80	127	285	164	306	213	326	263	345	315	364	374	383	447	398
90	136	295	175	315	227	337	276	358	336	378	400	396	475	414
100	142	305	185	326	238	348	290	371	352	390	422	409	500	425
110	150	315	195	335	250	357	305	382	372	402	441	421	525	438
120	157	322	202	344	259	366	323	392	392	412	465	431	550	450

APPENDIX D
Sprinkler Irrigation System Design Example

Design a sprinkler irrigation system to apply water to the 600- by 600-foot field shown in Figure D.1. The farmer is growing truck crops predominately peppers and eggplants on a Hagerstown soil in the central region of PA. Use a design ET rate of 0.2 in/day and a root depth of 12 inches. The maximum time available each day for irrigation is 12 hours. The water source is the pond shown in the northwest corner of the map with a water elevation of 580 feet.

Figure D.1. Map for Sprinkler Example:



Step 1. Decide what crops the grower wishes to irrigate and in what fields these crops will be grown. The dimensions of each field and the slopes and relative elevations of each field will be needed. A scaled sketch of the fields and their relationship to the proposed water supply is highly desirable.

Sprinkler Example: A simple topo map, as shown in Figure D.1, can be very helpful.

Step 2. Investigate and confirm the availability of an adequate water supply. Data and procedures in Chapter 4 will help the grower and designer determine how much water may be needed for irrigation of the desired crops.

Sprinkler Example: Based on the water needs outlined in Chapter 4, it is possible to estimate the volume of water needed to irrigate this 8.3-acre field. From Table 4.1, the total water depth needed maybe as large as 18.7 inches for the peppers and 19.6 inches for the eggplants. Using the larger of these two potential water needs (19.6"), if there is no rain at all during the growing season, the volume of water needed for irrigation could be as high as 163 ac-in or 13.6 ac-ft.

Based on the statistical weather data, the net water depth needs from Table 4.1 for these crops during a growing season if the design is based on a "normal" rainfall year will be between 9.2 and 9.6 inches or about 6.6 ac-ft of irrigation water. If the design is based on a "dry" rainfall year, the net water depth need will be between 10.5 and 10.7" or about 7.4 ac-ft. The example statement assumes plenty of water is available in the supply pond.

Step 3. Establish the global parameters for the crop(s) to be irrigated and the soils where this (ese) crops will be grown. The two parameters that should be used as a starting point in the design are the design depth (DD) and irrigation interval (II) developed in Chapter 6, Section c.1.

Sprinkler Example: From Equations 6.1 and 6.2, with the AWC in the root zone of 2.4 in/ft, management allowable depletion of 50% and water application efficiency of 70%, the DD = 1.7 inches of water to be applied every, II = 6.0 days.

Step 4. Select the water distribution method to be used. This section will focus on how to execute an irrigation design for a solid set or portable irrigation system.

Step 5. Develop the overall, system wide management decisions based on the crop, the soil, and the desires of the irrigator.

Sprinkler Example: The irrigation system has a DD = 1.7 inches (for Hagerstown soil and a 12-inch effective root depth) and an II = 6 days. The operator has specified that the irrigation system shall not be operated more than 12-hr/day during 7-day workweeks. Develop a list of the possible application rates and select one that will work well.

Solution: By substituting DD = 1.7 in; H_a = 12 hr/day into Equation 6.6 for S_d = 1, 2, . . ., the following table was developed:

S_d	A_r
1	0.14
2	0.28
3	0.42
4	0.56
5	0.71
6	0.85

The limits imposed on the application rate are a minimum of 0.2 in/hr. and a maximum of 0.7 in./hr (see Table 2.1 for Hagerstown soil). Based on Table 2.1, we could allow the design application rate to go as high as 0.7 in/hr. Therefore, selecting 5 or more sets/day is unacceptable because they yield application rates higher than the maximum infiltration rate. Also, because 1 set/day yields an application rate that is less than 0.20 in/hr, 1 set/day should be avoided. Thus 2, 3, or 4 sets/day could be chosen. From the above table, it can be seen that if 2 set/day is selected the application rate will be 0.28 in/hr to effectively utilize the 12 hr/day available. Since smaller numbers of sets reduces the number of set changes, thus reducing the labor cost, 2 sets/day will be selected (many growers may desire the fewest moves per day to reduce labor costs).

This irrigation system will be designed to apply a DD = 1.7 inches every 6 days at an A_r = 0.28 in/h which yields a T_s = 6 hr. or 2 set/d and 12 sets/II. Therefore, the field should be divided into 12 equal parts.

Step 6. Select the sprinkler spacing; distance between laterals and distance between sprinklers on each lateral.

Sprinkler Example. Select an appropriate spacing between the laterals (L) and the spacing between the sprinklers (S) for this irrigation system.

Solution: The field is square and if we run laterals parallel to the north or east side of the field, the laterals will run downhill from the supply main, which would run along the edge of the east or north side, respectively, of the field. Either layout will work in this case. It was decided to run the laterals parallel to the east side of the field, with the supply main located along the north side of the field. The lateral(s) will connect to the main on the north side of the field.

The next step is choosing an appropriate spacing; S x L. Since 12 sets are needed, the spacing between the laterals is best chosen as 600/12 = 50 feet. Since the field is square, make the spacing between the sprinklers on the lateral to be 50 feet. This yields a square 50’ by 50’ spacing where the first 50 is the distance between the sprinklers on the lateral, S and the second 50 is the distance between the laterals, L. To make the best use of the pipe and sprinklers and to maximize the uniform coverage of the field, the laterals and the sprinklers on each lateral are usually located a half-spacing from the edge of the field. This means there will be a small amount of sprinkler over-through on to the areas adjacent to the field. (Another option would be to design to use full length of irrigation piping and make the spacing fit the uncut pipe lengths.)

Step 7. Select the exact sprinkler to be used.

Sprinkler Example. Select the best available sprinkler (from Appendix C) for the example irrigation system. From earlier analyses, a 50- by 50-foot spacing has been selected and the system is to apply water at an application rate of 0.28 inches/hour. Select the best sprinkler from those presented in Appendix C.

Solution: Use Equation 6.8 to determine the required sprinkler discharge:

$$Q = \frac{(S \times L)A_r}{96.3} = \frac{(50)(50)(0.28)}{96.3} = 7.3gpm$$

The sprinkler should have a wetted diameter of at least (Eq. 6.7) of 77 feet, with the goal of 100 feet or more.

From Appendix C the sprinklers that might serve this purpose are:

Sprinkler	Nozzles (in)	Pressure (psi)	Q (gpm)	WD (ft)
C1	11/64	75	7.3	100
C2	3/16	52	7.3	100
C3	13/64	37	7.3	98
D1	5/32 x 3/32	57	7.3	102
D2	11/64 x 3/32	43	7.3	103

The five sprinklers in the table above are the only sprinklers that satisfy the requirements of this system. All have a flow rate of 7.3 gpm. All operate within the manufacturer's proper pressure range. All have wetted diameters greater than 77 feet, and all meet the desired 100-foot wetted diameter. In this case, it comes down to operating pressure and whether there is something better with a single or double nozzle sprinkler. Sprinkler C3 needs the lowest pressure and might be the best choice from a pressure standpoint. Sprinkler D2 has a very low pressure and has a larger (103-foot) wetted diameter. Either C3 or D2 would do a good job. Because of the larger wetted diameter of "D2", sprinkler "D2" to operate at 43 psi is the best choice.

Step 8. On a scaled drawing of the field(s), with elevations of key locations shown, layout where the laterals and sprinklers will be located. Also include on the field map, the proposed location of the pump, suction line and main. This step is critical as we move toward pipe sizing.

Sprinkler Example Earlier in Step 6, when the 50- by 50-foot sprinkler spacing was chosen, it was decided to place the main supply pipe along the north edge of the field and run the laterals parallel to the east edge of the field. The first and last laterals and the first and last sprinklers on each lateral will be placed a half-spacing from the edge of the field.

Locate the main along the north edge of the field. Locate the pump. Add a connector pipe from the pump to the main (this is also part of the main), see Figure D.2.

Step 9. Properly size the laterals.

Sprinkler Example Size the lateral needed to provide water to the 12 sprinklers on each lateral.

Solution: Because this is a portable system, aluminum pipe will be used throughout. The lateral to be used to supply the 12 sprinklers with water will be 11.5(50) = 575 feet long. The total flow into the lateral from the main will be 7.3(12) = 88 gpm. The C_f for 12 sprinklers is 0.388, from Table 6.2. $\Delta Z = Z_m - Z_e$ = 590 ft - 584 ft = +6 ft (west side) or $\Delta Z = Z_m - Z_e$ = 579 ft - 574 ft = +5 ft (east side); best to use the smaller elevation difference of +5 feet. The operating pressure of the sprinklers is 43 psi.

Substituting into Equation 6.19 yields:

$$F_{cd} = \frac{23.5(43\,psi) + 45.5(+5\,ft) + 63}{575\,ft(0.388)} = 5.83\,psi/100\,ft$$

Looking to the Aluminum pipe chart in Appendix B, with Q = 88 gpm and the maximum friction factor = 5.83 psi/100 ft yields a minimum sized lateral of 3.0 inches.

Step 10. Properly size the main transmission pipelines and the suction line if necessary.

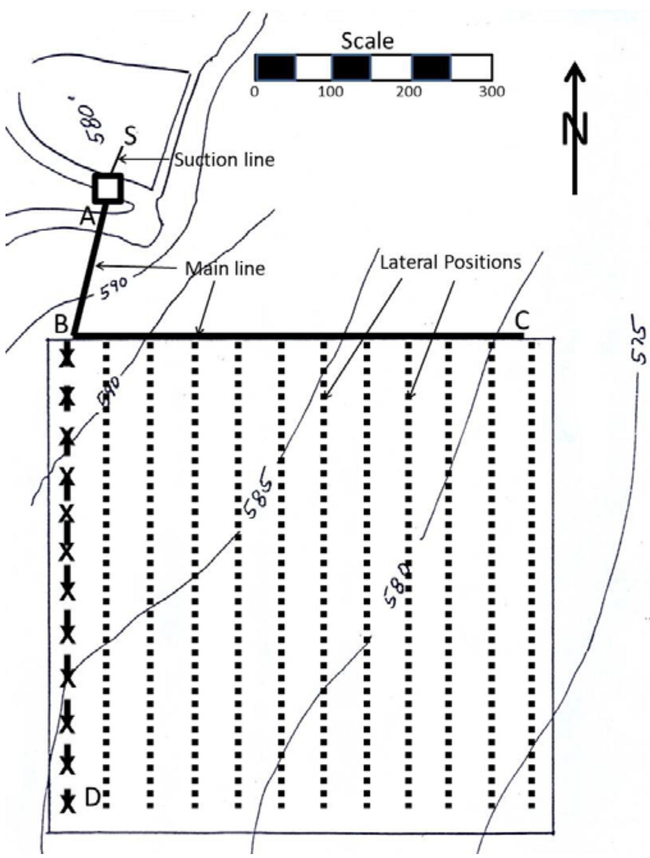
Sprinkler Example Size the main needed to provide water to the lateral in each of its 12 locations. Then properly size the suction line.

Main Line Solution: To size the main for this supplemental portable irrigation system used <4,000 hr./yr. from Figure 6.7, and the design friction factor should be 1.0 psi/100 ft. With an 88 gpm flow rate, this yields 4-inch diameter aluminum pipe for the main.

Suction Line solution: Assuming the pump for this system will be located on the bank of the supply pond, a suction pipe will be needed. Since the main is sized to be 4 inches in diameter, the suction line should be 5 inches in diameter.

The following Figure D.2 shows the proposed location of the suction pipe, the main line and the lateral in its first position with the 12 sprinklers on the lateral.

Figure D.2 Map 2 for sprinkler example:



Step 11. Determine the pump requirements for the most critical location in the field.

Sprinkler Example Determine the pump requirements for the example design problem; Q and H_T.

Solution: To determine the pump requirements, H_T for this example Bernoulli's Equation must be written from the water source to the critical location on the main. In this example, it is difficult to determine whether Point B or C is the critical location on the main (the point that will require the most pump energy). The safe thing to do is to calculate H_T for both points and use the larger value. Start by writing the Bernoulli Equation 6.22 from Point S to Point B.

$$Z_S + 2.31 p_S + H_T = Z_B + 2.31 p_B + H_{L_{StoB}}$$

Substitute the known information into this equation and solve:

580 ft +2.31(0) + H_T = 590 ft + 2.31(43 psi) + 0.28psi/100ft(175ft)(2.31) + 10%H_L

or 580 ft + 0 + H_T = 590 ft + 99.3 ft + 1.1 ft + 0.1 ft

solving for H_T = 110.5 ft

For Point C, Bernoulli's Equation is:

$$Z_S + 2.31 p_S + H_T = Z_C + 2.31 p_C + H_{L_{StoC}}$$

Again, substitute the known information into this equation and solve:

580 ft +2.31(0) + H_T = 579 ft + 2.31(43 psi) + 0.28psi/100ft(760ft) (2.31) + 10%H_L

or 580 ft + 0 + H_T = 579 ft + 99.3 ft + 4.9 ft + 0.5 ft

solving for H_T = 103.7 ft

Therefore, the required pump energy is 110.5 feet (the larger of the two calculations). The required pump discharge is 88 gpm.

Step 12. Select a pump and power unit to provide energy to the water being pumped to the irrigation system.

Sprinkler Example The pump, whose curve is shown in Figure D.3 will be used to provide the energy for this example. With an H_T = 110.5 feet and a design flow rate, Q = 88 gpm, the design point on the curve would suggest that we should use the 5 1/2-inch impellor, which will yield an efficiency of about 45%. By using Equation 6.24 we can compute the horsepower requirement for our system as:

$$H_p = \frac{H_T Q}{3960(E_t)} = \frac{(110.5)(88)}{3960(.45)} = 5.4 \text{ HP}$$

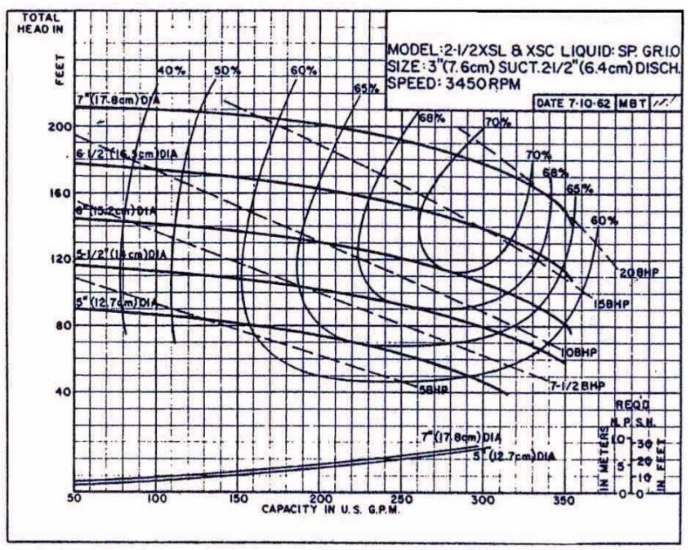
The horsepower equation yields a need for 5.4 hp. It is not unusual to oversize the power unit, or at least round the results of the power equation up to the next larger size power unit size, probably 7.5 hp.

By taking the total head of 110 feet and the required discharge of 88 gpm to the presented pump curve, it is discovered that this pump will supply this irrigation system, but at a very low efficiency. Therefore, the best advice is to contact a pump distributor who may be able to suggest a better and more efficient pump.

Step 13. Within the decisions already made, learn how to properly decide when and how much water needs to be applied through the irrigation system.

This step was discussed in Chapter 9 where management of the irrigation system was covered.

Figure D.3. Centrifugal Pump Curve.



APPENDIX E
Drip Irrigation Example Using Line-Source Emitters

Line-Source Drip Example Design a drip irrigation system to apply water to the 600- by 600-foot field shown in Figure E.1. The farmer is growing truck crops predominately peppers and eggplants with an average canopy width of 2 feet on a Hagerstown soil in the central region of PA. Use a design ET rate of 0.2 in/day and a root depth of 12 inches. The maximum time available each day for irrigation is 12 hours. The water source is the pond shown in the northwest corner of the map with a water elevation of 580 feet. The various truck crops are growing in rows spaced 3 feet apart running from north to south in the field. The average canopy width is 2 feet.

Step 1. Decide what crops the grower wishes to irrigate and in what fields these crops will be grown. The dimensions of each field and the slopes and relative elevations of each field will be needed. A scaled sketch of the fields and their relationship to the proposed water supply is highly desirable.

> **Line-Source Drip Example**: A topo map, as shown in Figure E.1, can be most helpful.

Step 2. Investigate and confirm the availability of an adequate water supply. Data and procedures in Chapter 4 will help the grower and designer determine how much water may be needed for irrigation of the desired crops.

> **Line-Source Drip Example**: Based on the water needs outlined in Chapter 4, it is possible to estimate the volume of water needed to irrigate this 8.3-acre field. From Table 4.1, the total water depth needed maybe as large as 18.7 inches for the peppers and 19.6 inches for the eggplants. Using the larger of these two potential water needs (19.6”), if there is no rain during the growing season, the volume of water needed for irrigation could be as high as 163 ac-in or 13.6 ac-ft.
>
> Based on the statistical weather data, the net water depth needs from Table 4.1 and 4.2 for these crops during a growing season if the design is based on a “normal” rainfall year will be between 9.2 and 9.6 inches or about 6.6 ac-ft of irrigation water. If the design is based on a “dry” rainfall year, the net water depth need will between 10.5”-10.7” or about 7.4 ac-ft. The example statement assumes plenty of surface water is available in the supply pond.

Step 3. Establish the global parameters for the crops to be irrigated and the soils that will be used to grow these crops. The two parameters that should be used as a start point in the design are the design depth and irrigation interval developed in Chapter 6, section c.1.

> **Line-Source Drip Example (Cont’d)**: Using the procedures developed in Chapter 6, Section c.1 for the Hagerstown soil, (AWC = 2.4 inches for a 12-inch effective root depth) the II = 6.0 days, this is the maximum number of days between irrigations. Because this is a drip system, with a water application efficiency of 90%, the design depth, DD = 1.3 inches. As a drip system, the maximum depth of water to be applied is 1.3 inches every 6 days. This assumes that there will be no natural precipitation.

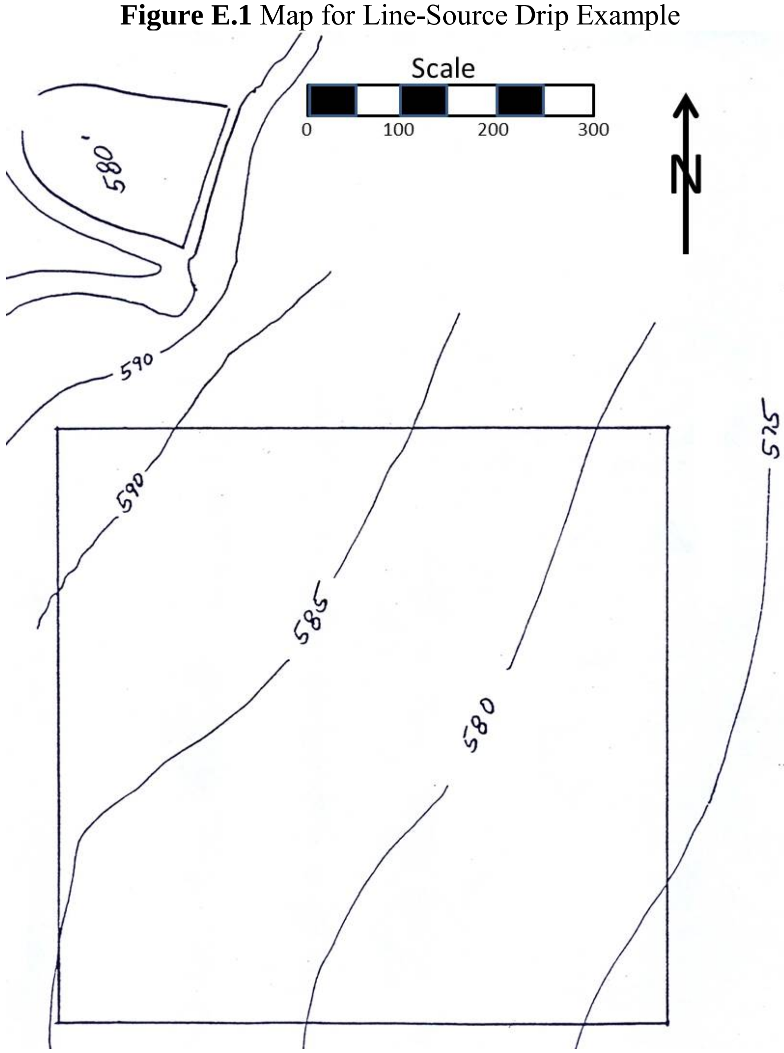
Step 4. Select the water distribution method to be used. This section will focus on how to execute an irrigation design for a drip irrigation system.

> **Line-Source Drip Example**: A drip system with line source emitters has been selected and will be designed.

Step 5. Develop the overall, system wide management decisions based on the crop, the soil, and the desires of the irrigator. With drip irrigation systems, the time/set, T_s, sets/day, S_d, and sets/cycle, S_w are often viewed differently. Instead of considering one application of water every irrigation interval, II, growers often think in terms of applying the needed water more often. Many drip irrigators will apply the water needed by the plants every day or every other day. This means the drip system may be used to apply smaller depths of water more frequently.

> **Line-Source Drip Example:** In this example instead of applying 1.3 inches of water every 6 days, it might be better to consider applying (0.2/0.9) = 0.22 inches of water every day, thus the whole field will be irrigated every day, as one set. Or applying 0.44 inches of water every two days, thus half of the field will be irrigated every day; the whole field will be irrigated every other day. For purposes of this example, based on input and the desires of the grower, it was decided to irrigate every other day, so the design will be based on creating the ability to apply 0.44 inches of water to half of the field every day. The whole field will be irrigated every other day.

Figure E.1 Map for Line-Source Drip Example



Step 6. Determine the row spacing and the average width of the crop canopy for each crop.

Line-Source Drip Example:

Rows of vegetables are spaced 3 feet apart; therefore, there are 200 crop rows in the field. The average canopy width is 2 feet. Therefore, each row has a canopy area of 2 x 600 = 1,200ft^2.

Step 7. Select the exact line-source emitter system to be used to irrigate this field.

Line-Source Drip Example

First examine each crop row. Each row is 600 feet long and has a width of 2 feet yielding an area to be irrigated of 1200 ft^2. Or, in preparation for looking at data supplied by a drip tape supplier, this is 200 ft^2/100 feet of length (A or area based on the 100ft length of pipe). At 0.44 inches (D_d) of water depth to be applied in a maximum of 12 hours (H_a), Equation 6.30 yields a minimum drip tape flow rate of:

$$Q = \frac{A(D_d)}{1.6H_a} = \frac{200(0.44)}{1.6(12)} = 4.56 \text{ gph/100 feet} = 0.076 \text{ gpm/100 feet}$$

Before a specific drip tape can be selected for this application, the most appropriate emitter spacing needs to be determined. Since our the soil is Hagerstown, which is a silty clay loam, Table 6.8 shows that a single emitter will wet a circle that is 6 feet in diameter. Therefore, to choose an emitter spacing of 3 or 4, or even 5 feet should work well.

However, with an average rooting depth of only 12 inches, a 3- to 5-foot emitter spacing will probably yield non-uniform water contents to the row crops. With shallow rooted crops, 2-foot emitter spacings are about the widest one should go with the emitters. The 2-foot (24-inch) emitter spacing is recommended.

The next step is to go to the manufacturer's drip catalog and look for a line-source drip tape with pressure compensating emitters spaced 2 feet apart or closer with a flow rate of 4.56 gph/100 feet or 0.076 gpm/100 feet or an equivalent.

After searching several distributors' catalogs, a pressure-compensating emitter imbedded in an 18-mm diameter PE drip tape with the emitters spaced every 24 inches (50 emitters per 100 ft) was selected. Each emitter discharges 0.42 gph, which equals 0.350 gpm for every 100 feet of drip tape. (0.42gph(50emitters))/100ft= 21gph/100ft = 0.35 gpm/100ft.

The irrigation water should be introduced into the upslope end of each lateral at a pressure of 10 psi. The laterals will be 600 feet long. According to the manufacturer's data, the friction in each 600-foot lateral will be about 5 psi. With the laterals sloping downward an elevation change of, on average 6 feet, there should be a nearly uniform pressure throughout each entire lateral (head loss = 5 psi = 11.5 feet versus an elevation gain of 6 feet), therefore the pressure at each emitter on each 600-foot lateral will be 10 psi plus or minus maximum of 2.0 psi. This is a good design.

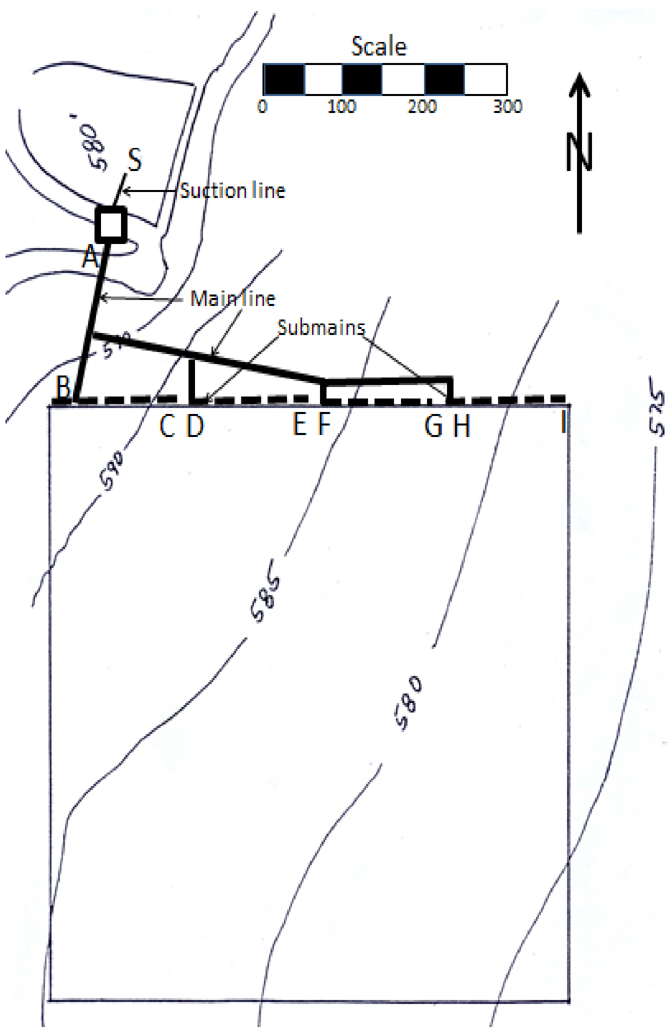
The calculation above shows that to irrigate a set in 12 hours, we will need a flow rate of 0.076 gpm/100 feet or (6(0.076) = 0.456 gpm/600 feet of lateral. Since the chosen emitters will apply the 0.44 inches of water in 2.6 hours (H_a) = (200) (0.44")/ (1.6(21gph)) the management plan can be adjusted.

A better approach might be to split the field into 4 equal sets, 50 laterals in each set. Each of the four sets could be run every other day for 2.6 hours or, possibly more convenient, run Set 1 in the morning of Day 1 for 2.6 hours and then run Set 2 in the afternoon of Day 1 for 2.6 hours. This will be repeated during Day 2 for Sets 3 and 4. With this plan, each lateral will need 6(0.350) gpm = 2.1 gpm and each set of 50 laterals will need a flow rate of 105 gpm.

Step 8. On a scaled drawing of the field(s), with elevations of key locations known, layout where the laterals will be located. Also include on the field map, the proposed location of the pump, suction line and main. This step is critical for pipe sizing.

Line-Source Drip Example: This drip tape/lateral layout is too detailed to show here on this sketch. The most important result is that the 4 sets of 50 laterals each be shown on the map, see Figure E.2.

Figure E.2 Line-Source Drip Example.



Step 9. Properly size the laterals.

Line-Source Drip Example: Each lateral has already been sized by virtue of choosing the 18-mm diameter drip tape. The pressure distribution within each lateral was discussed above.

Step 10. Properly size the main transmission pipelines, the submains, and the suction line if necessary.

Line-Source Drip Example: The main transmission line needed to carry water from the pump to each of the four sets has two parts. First the submain to carry water to the inlet end of the 50 laterals must be sized. One submain will be needed for each set. Second, the pipe to carry the 105 gpm to each of these four submains must be sized.

To properly size the submain, B-C, for example, Equation 6.19 from Chapter 6 should be used. To determine the maximum allowable friction factor for each submain (which are actually laterals) the following parameters are needed:

- Design pressure at each emitter, P = 10 psi.
- The elevation difference between the upslope end of the submain, Z_m and the downslope end of the submain, Z_e. For submain B-C, Z_m = 590 ft and Z_e = 589 ft, so ΔZ = 1 foot. For the other submains, ΔZ averages about 4 feet. Since the flatter sloped submain will require the larger pipe, we will design for ΔZ = 1 feet.
- The submain length, L = 150 feet, and
- $C_f(50)$ = 0.355 (Table 6.2)

Therefore, the design friction factor for the submain is:

$$F_{cd} = \frac{23.5P + 45.5\Delta Z + 63}{LC_f} = \frac{23.5(10) + 45.5(1) + 63}{150(0.355)} = 6.45 \text{ psi/100ft}$$

By choosing PVC Schedule 40 pipe for the submain carrying 105 gpm will need to be 2.5-inch pipe (F_c = 2.9 psi/100 ft). Since the other submains, D-E, F-G, and H-I has a steeper slope (ΔZ = 4 feet), F_{cd} = 9.0 psi/100ft, a 2-inch PVC Schedule 40 pipe would be okay for the other submains.

The main, from the pump to the entrance to each submain will need to be based on a design F_{cd} = 1.0 psi/100 ft, or 3-inch diameter PVC Schedule 40 pipe. Therefore, the suction pipe should be a 4-inch pipe.

Step 11. Determine the pump requirements for the most critical location in the field(s); usually the highest elevation.

Line-Source Drip Example: The Figure E.2 above shows a suction line, pump and PVC Schedule 40 main to deliver 105 gpm of irrigation water to each of four submains. There are 50 laterals connected to each submain. The pressure at the beginning of each submain is 10 psi with the intent (via proper design) that the pressure where each lateral connects to the submain will also be 10 psi. The pump energy should be computed for Point B (Z_B = 590 ft). The water to supply this irrigation system is to come from the pond shown as Point S at an elevation of 580 ft. Determine the maximum pump head needed to deliver irrigation water to Point B. The pressure required at point B is 10 psi.

Solution: To determine the pump energy head needed to run this system, write Bernoulli's equation between the source (S) and B. First compute the energy lost to friction between the Pump and Point B:

$H_L = F_c L$
$H_L = (1.0 \text{ psi}/100 \text{ ft})\ (300 \text{ ft}) = 3.0 \text{ psi} = 7.0$ ft of head loss.

To determine the pump energy required first write Equation 6.20 from point S to point B as

$$Z_S + 2.31 p_S + H_T = Z_B + 2.31 p_B + H_{L_{StoB}}$$

Substituting the known information into this equation we get

$580 \text{ ft} + 2.31(0) + H_T = 590 \text{ ft} + 2.31(10\text{psi}) + 7.0 \text{ ft} + 10\%\ H_L$

or $580 \text{ ft} + 0 + H_T = 590 \text{ ft} + 23.1 \text{ ft} + 7.0 \text{ ft} + 0.7 \text{ ft}$

Therefore, H_T between the source and Point B = 40.8 feet.

Because the water supply for this drip system is surface water stored in a pond, it will be necessary to filter the water before it is delivered to the drip distribution system. The sand filters required to filter 105 gpm require 120 psi of pressure just to properly operate the filters. This additional 120 psi should be added to the irrigation system pressure requirements, thus the H_T for this system is 41 feet + 277 feet = 318 feet.

Step 12. Select a pump and power unit to provide energy to water being pumped to the irrigation system.

Line-Source Drip Example: In most cases the drip system distributor will provide the pump and power unit to supply the entire system.

Step 13. Within the decisions already made, learn how to properly decide when and how much water needs to be applied through the irrigation system.

Line-Source Drip Example: The basis upon which these decisions should be made was covered in Chapter 9.

APPENDIX F
Point-Source Drip Design Example

Point-Source Drip Example Design a drip irrigation system to apply water to the 600- by 600-foot field shown in Figure F.1. The grower has an apple orchard on this Hagerstown soil field in the central region of PA. Use a design ET rate of 0.2 in/day and a root depth of 30 inches. The maximum time available each day for irrigation is 12 hours. The water source is the pond shown in the northwest corner of the map with a water elevation of 580 feet. The apple trees are growing in rows spaced 20 feet apart running from north to south in the orchard. The trees are spaced 15 feet apart in each row. The tree canopies just touch within each row of trees.

Step 1. Decide what crops the grower wishes to irrigate and in what fields these crops will be grown. Gather the dimensions of each field and the slopes and relative elevations of each field. A scaled sketch of the fields and their relationship to the proposed water supply is highly desirable.

Point-Source Drip Example: A simple topo map, as shown in Figure F.1, can be most helpful.

Step 2. Investigate and confirm the availability of an adequate water supply. Data and procedures in Chapter 4 will help the grower and designer determine how much water may be needed for irrigation of the desired crops.

Point-Source Drip Example: Based on the water needs outlined in Chapter 4, it is possible to estimate the volume of water needed to irrigate this 8.3-acre orchard. From Table 4.1, the total water depth needed maybe as large as 33.2”. If there is no rain during the entire growing season, the volume of water needed for irrigation could be as high as 275 ac-in or 23 ac-ft.

Based on the statistical weather data, the net water depth (seasonal irrigation) needs from Table 4.1 for this orchard during a growing season if the design is based on a “normal” rainfall year will be 18.1” or 12.5 ac-ft. If the design is based on a “dry” rainfall year the net water depth need will be 20.1” or 13.9 ac-ft. The example statement assumes plenty of surface water is available in the supply pond.

Step 3. Establish the global parameters for the crops to be irrigated and the soils that will be used to grow these crops. The two parameters that should be used as a start point in the design are the design depth and irrigation interval developed in Chapter 6, section c.1.

Point-Source Drip Example: Following the approach developed in Chapter 6, section c.1, with the Hagerstown soil (AWC = 5.0 inches (estimated) for the 30-inch effective root depth) the II = 12.5 days, this is the maximum number of days between irrigations. Because this is a drip system, with a water application efficiency of 90%, the design depth, DD = 2.8 inches. The maximum depth of water to be applied is 2.8 inches every 12.5 days.

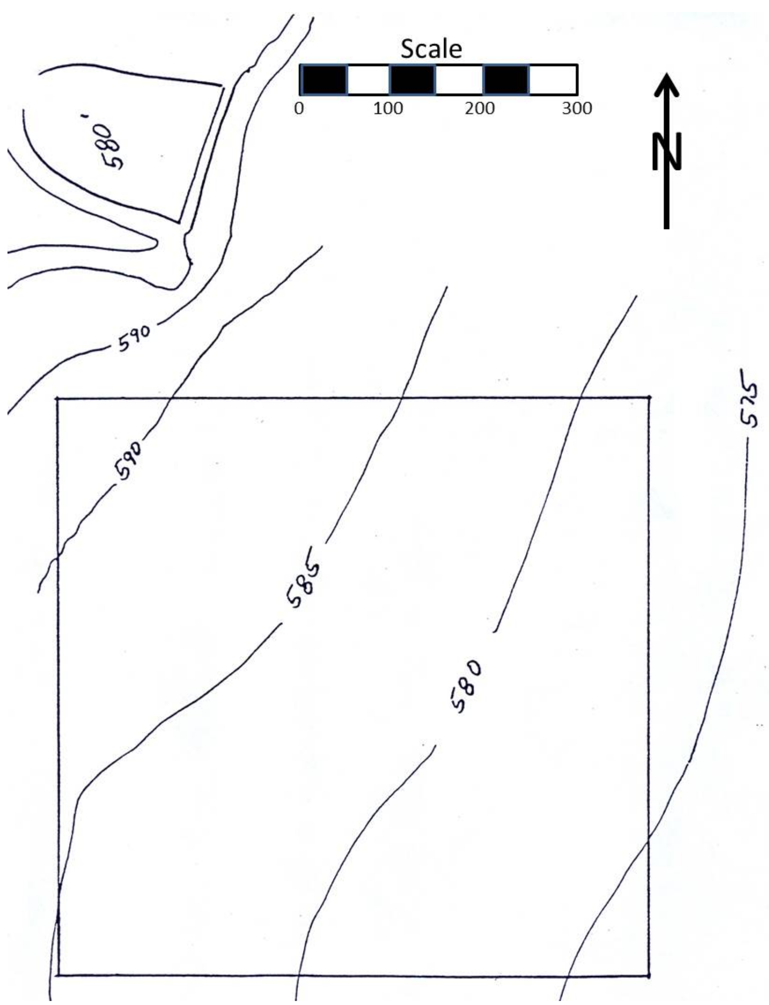
Step 4. Select the water distribution method to be used. This section will focus on how to execute an irrigation design for a drip irrigation system.

Point-Source Drip Example: A drip system with point-source emitters has been selected and will be designed.

Step 5. Develop the overall, system wide management decisions based on the crop, the soil, and the desires of the irrigator. With drip irrigation systems, the time/set, T_s, sets/day, S_d, and sets/cycle, S_w are often viewed differently than for sprinkler irrigation. Instead of considering one application of water every irrigation interval, II, growers often think in terms of applying the needed water more often. Many drip irrigators will apply the water needed by the plants every day or every other day. This means the drip system may be used to apply smaller depths of water more frequently.

> **Point-Source Drip Example:** In this example these changes mean that instead of applying 2.8 inches of water every 12.5 days, the grower should consider applying 0.22 inches of water every day, thus the whole orchard will be irrigated every day, as one set. Or applying 0.44 inches of water every two days, thus half of the orchard will be irrigated every day; the whole orchard will be irrigated every other day. Or apply 2.8 inches of water to 1/10 of the orchard, thus irrigating the whole orchard in 10 days and leaving 2 days out of every 12 days when no irrigation water will be applied. For purposes of this example, 1/10 of the orchard will be irrigated every day, thus applying 2.8 inches of water to 1/10 of the orchard (3 rows of trees) every day. The whole orchard will be irrigated every 12 days.

Figure F.1 Point-Source Drip Example



Step 6. Determine the plant spacing and the average area of the plant canopy for each plant.

Point-Source Drip Example: The rows of trees are spaced 20 feet apart; therefore, there are 30 rows of trees in the orchard. The trees are planted 15 feet apart and the tree canopies just touch between trees in each row.

Step 7. Select the exact point-source emitter system to be used to irrigate this field.

Point-Source Drip Example: First develop the requirements for each tree. Each tree has a canopy diameter of 15 feet yielding a canopy area for each tree of 177 ft^2. In preparation for looking at data supplied by a drip emitter supplier, begin by using Equation 6.30 for one tree:

$$Q = \frac{A(D_d)}{1.6H_a} = \frac{177(2.8)}{1.6(12)} = 25.8 \text{ gph/tree}$$

Before appropriate drip emitters can be selected for this application, it is necessary to determine how many emitters should be located under each tree. Since the soil is Hagerstown, which is a silty clay loam, Table 6.8 shows that a single emitter will wet a circle that is 6 feet in diameter, or about 28 ft^2/emitter. Therefore, to wet the root volume under the 177 ft^2 area of each tree, the designer should plan to place a minimum of 2 or as many as 6 emitters under each tree. The minimum number of emitters comes from the fact that the water needs to wet a minimum of 25% (33-50% sometimes chosen) of the root volume ¼ (177 sq. ft)/28 sq. ft per emitter = 2. The maximum number comes from seeking to wet essentially the whole root volume (177 sq. ft/28 sq. ft per emitter = 6).

From a manufacturer's drip catalog, look for point-source pressure compensating drip emitters that have design flow rates of between 4.3 gph (6 emitters) and 12.9 gph (2 emitters) or an equivalent.

The available pressure compensating point-source emitters have flow rates of either 0.5, 1.0, or 2.0 gph. If the 2.0 gph flow rate emitters are chosen, 13 emitters/tree will be needed, (25.8/2.0) = 13, each operating at 20 psi.

Step 8. On a scaled drawing of the field(s), with elevations of key locations known, layout where the laterals and sprinklers will be located. Also include on the field map, the proposed location of the pump, suction line and main. This step is critical if pipe sizing is to follow.

Point-Source Drip Example: The sketch of the orchard showing Sets 1 and 10 and a detail of one tree's emitter placement is shown in Figure F.2.

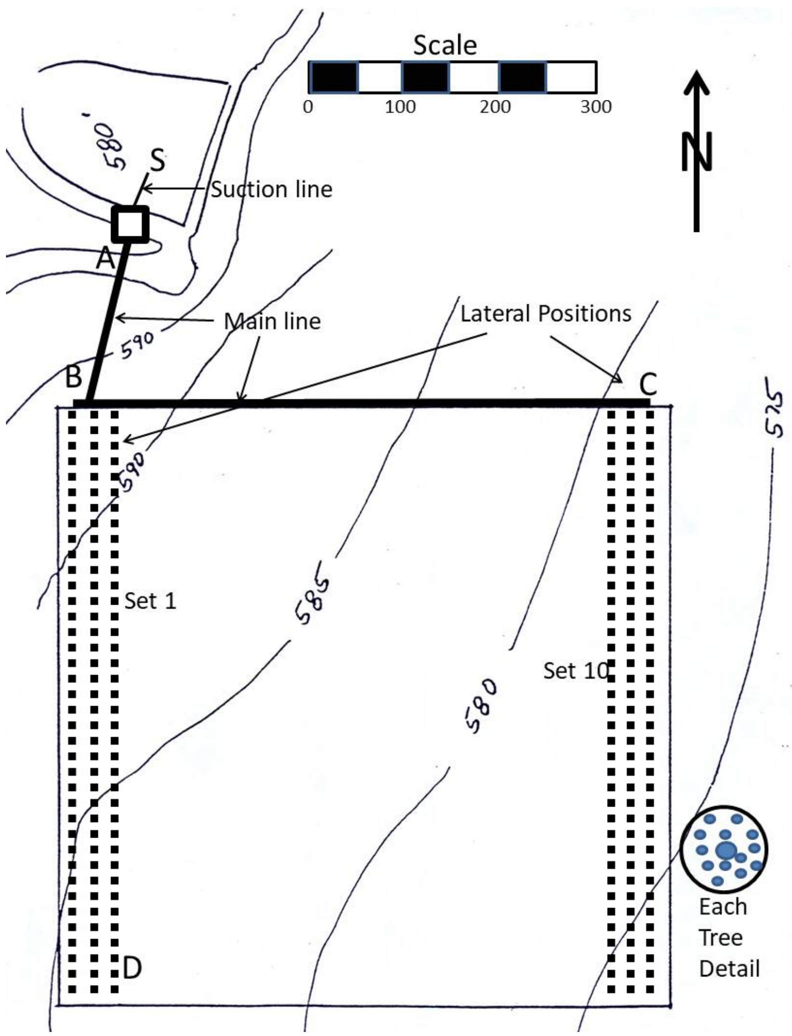
Step 9. Properly size the laterals.

Point-Source Drip Example: Each of the 30 rows of trees will have 40 trees with 25.8 gph/tree. Each row of 40 trees will have its own lateral carrying 40 x 25.8 gph = 17.2 gpm (0.43 gpm/tree). Each tree will have a central distribution point with 13 small PE lines, one to each emitter. (Another option may utilize fewer devises for grower ease of weed control or harvest.)

To properly size each lateral, Equation 6.19 should be employed. To determine the maximum allowable friction factor for each lateral, the following parameters are needed:

- Design pressure at each emitter, P = 20 psi.
- The elevation difference between the upslope end of the lateral, Z_m and the downslope end of the lateral, Z_e. For Set 1, the laterals have elevations of, Z_m = 590 ft and Z_e = 584 ft, so ΔZ = +6 feet. For Set 10 the lateral has elevations of, Z_m = 579 ft and Z_e = 575 ft, thus ΔZ = +4 feet. Since the flatter sloped lateral will require the larger pipe, we will design for ΔZ = +4 feet.
- The lateral length, L = 600 feet, and
- $C_f(40)$ = 0.359 (Table 6.2)

Figure F.2 Point-Source Drip Example



Therefore, the design friction factor for the lateral is:

$$F_{cd} = \frac{23.5P + 45.5\Delta Z + 63}{LC_f} = \frac{23.5(20) + 45.5(4) + 63}{600(0.359)} = 3.32 \text{ psi/100ft}$$

By choosing PE pipe for the laterals carrying 17.3 gpm will need to be 1.5-inch pipe (F_c = 2.8 psi/100 ft), by interpolation on Table B.8.

Step 10. Properly size the main transmission pipelines and the suction line if necessary.

Point-Source Drip Example: The main, from the pump to the entrance to each lateral will need to be based on a design F_{cd} = 1.0 psi/100 ft, for 52 gpm (3 laterals/set) or 2.5-inch diameter PVC Schedule 40 pipe, Table B-3. Therefore, the suction pipe should be a 4.0-inch pipe, PVC Schedule 40.

Step 11. Determine the pump requirements for the most critical location in the field(s); usually the highest elevation.

Point-Source Drip Example: Figure F.2 shows a suction line, pump and main to deliver 52 gpm of irrigation water to each of 10 sets. There are 30 laterals connected to the main. The pressure at the beginning of each lateral is 20 psi with the intent (via proper design) that the pressure where each lateral connects to the main will also be 20 psi. The pump energy should be computed for both Points B (Z_B = 590 ft) and C (Z_C = 579 ft). The water to supply this irrigation system is to come from the pond shown as Point S at an elevation of 580 ft. Determine the maximum pump head needed to deliver irrigation water to both Point B and C (each set runs separately). The pressure required at point B and Point C is 20 psi.

Solution: To determine the pump energy head needed to run this system, write Bernoulli's equation, Equation 6.22 between the source (S) and B and then repeat it for Points S and C. First compute the energy lost to friction between the Pump and Point B:

$H_L = F_c L$
H_L = (0.80 psi/100 ft)(250 ft) = 2.0 psi = 4.6 ft of head loss.

To determine the pump energy required first write Equation 6.22 from point S to point B as

$$Z_S + 2.31 p_S + H_T = Z_B + 2.31 p_B + H_{L_{StoB}}$$

Substituting the known information into this equation we get

580 ft +2.31(0) + H_T = 590 ft + 2.31(20psi) + 4.6 ft + 10% H_L

or 580 ft + 0 + H_T = 590 ft + 46.2 ft + 4.6 ft + 0.5 ft

Therefore, H_T between the source and Point B = 61.3 feet.

If this computation is repeated between the source and Point C, H_T = 62.5 feet. For all practical purposes these two requirements are the same. The pump should be sized to supply 62 ft of head at 52 gpm.

Because the water supply for this drip system is surface water stored in a pond, it will be necessary to filter the water before it is delivered to the drip distribution system. The sand filters required to filter 52 gpm require 120 psi of pressure just to properly operate the filters. This additional 120 psi should be added to the irrigation system pressure requirements, thus the H_T for this system is 62 feet + 277 feet = 338 feet.

Step 12. Select a pump and power unit to provide energy to water being pumped to the irrigation system.

Point-Source Drip Example: In most cases the drip system distributor will provide the pump and power unit to supply the entire system.

Step 13. Within the decisions already made, learn how to properly decide when and how much water needs to be applied through the irrigation system.

Point-Source Drip Example: the basis upon which these decisions should be made were covered in Chapter 9.

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