NEW JERSEY IRRIGATION GUIDE

United States Department of Agriculture
Natural Resources Conservation Service
Somerset, New Jersey

June 2005 (rev. May 2020)

Acknowledgment

This update of the September 1983 New Jersey Irrigation Guide was prepared by the New Jersey Irrigation Water Management Specialists, **MaryBeth Sorrentino** and **Rubén Pérez**. It has been formatted for compatibility with the NRCS National Engineering Handbook, Part 652, Irrigation Guide. This update contains several tables of original work including Net Irrigation Water Requirements for New Jersey crops and Crop Consumptive Use and Peak ET values.

Cover Photo by María M. Collazo, Resource Conservationist

June 2005

NEW JERSEY IRRIGATION GUIDE
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Chapter 1 Introduction

Contents **NJ652.01**

NJ652.01 Introduction

a) General Information

The New Jersey supplement to the National Engineering Handbook (NEH), Part 652, Irrigation Guide, has been adapted from the original New Jersey Irrigation Guide. The material was developed to assist New Jersey NRCS field personnel and others working with New Jersey irrigators to provide general planning, design, and management guidance on various methods of irrigation commonly used in the State. When the system is designed, installed, and operated in accordance with the basic factors, the irrigator is assured that the irrigation system will apply the needed amount of water without waste or damage to the land and maintain the soil fertility and water quality while achieving optimum yields. The irrigation planner must be aware that every irrigation system should minimize runoff and erosion and account for drainage. For example, usually a desirable system for hoophouse sprinkler irrigation is the use of stone lined channels to deliver tailwater runoff to a recovery basin and pump-back system. The need for erosion control and drainage should be kept fully in mind when developing the conservation irrigation plan. Section IV of the Field Office Technical Guide contains standards for conservation practices including irrigation practices such as Irrigation Water Conveyance, Sprinkler Systems, Micro-Irrigation and Tailwater Recovery Systems. The design of all irrigation systems shall follow the procedures in Part NJ652.06 and conform to the requirements outlined in the applicable New Jersey standards.

The New Jersey Irrigation Guide includes information and experience about soils, climate, water supplies, crops, cultural practices, and farming conditions in New Jersey. These basic factors must be evaluated in planning and design of an irrigation system.

Conservation irrigation is an integral part of a complete farm program of soil and water conservation.

The aim of irrigation is to eliminate water as a limiting factor in plant growth. This means that it should be used primarily on land of high potential productivity. Treatment with irrigation must include adequate fertilization and cropping systems that control erosion and leaching, and maintain good soil tilth and organic matter.

For the farmer, the benefits from irrigation must be sufficient to justify the cost of purchasing and operating the irrigation system and leave a reasonable return on the investment.

For the greens keeper, park or landscape superintendent, nurseryman, and homeowner, irrigation helps to maintain the desired growth of grass, ornamental plants, flowers, and garden crops with minimum cost and effort.

b) Considerations

To obtain the maximum benefits from irrigation, the following must be considered:

Soil

Several soil properties directly influence the design and operation of an irrigation system. They are: (a) water intake rate, (b) available water holding capacity of each significant soil layer or horizon, (c) depth.

Plant response to irrigation is influenced by the physical condition, fertility, and biological status of the soil. Physical condition or structure determines the extent to which a root system can develop by growing into and using the available moisture in the soil. The biological status is the condition produced by the relationships of the pH, organic matter, fertility, and available moisture in the soil.

Crops

Crops will respond to irrigation when the normal rainfall does not maintain favorable moisture levels. Benefits result from improved quality as well as increased productivity. Plant wilt and color changes are important indicators of plants that are under stress due to water deficiency. Knowledge of rooting depths, rates of water usage at different crop stages, and plant growth characteristics is necessary in determining when and how much to irrigate.

Water Supply

Irrigation requires large volumes of water, and the supply must be reliable. The quality of water as well as the quantity must be considered. If there is any question as to the quality of the water, it should be tested.

The right to water use by the landowner must also be considered when planning for irrigation. The landowner must be certain that he or she has a legal right to continued use of the water supply, particularly if it is a natural flowing stream or an underground source.

Drainage

Soils to be irrigated must have adequate drainage. If they do not have adequate natural drainage, artificial drainage measures must be installed. Otherwise, a heavy rainfall following irrigation may cause crop damage.

Erosion Control

If the area to be irrigated is on sloping land, provision must be made to control erosion. Erosion can be aggravated if a rain occurs immediately after irrigation. Needed conservation practices must be installed for erosion control.

Fertility Management

Soil fertility should be maintained at a high level so plants may fully utilize available moisture assured by irrigation. Fertilizer applications should be applied according to recommendations conforming to the nutrient management standards and specifications. Soil testing and leaf tissue analysis can be obtained through Rutgers Cooperative Extension Service.

Pests and Disease

Damage from insects may or may not increase under irrigation. Cutworms, leaf hoppers, thrips, and army worms may thrive under irrigated conditions.

Plant diseases usually increase with sprinkler irrigation. High humidity around plants and splashing water contribute to a more favorable environment for bacterial and fungus disease organisms. Irrigating at night further increases the potential for diseases.

The pesticide recommendations published by Rutgers Cooperative Extension Service provide guides for control of common insect pests. Integrated Pest Management Practices are encouraged for safe and efficient chemical applications.

c) An Irrigation System Plan

In order for an irrigation system to be successful, it must be planned to fit the site characteristics of soil, climate, and water supplies, plus the management requirements for agricultural, turf, or other proposed uses. Improvements and new methods of irrigation make irrigation possible under a wide range of conditions.

The irrigation system plan should take into account the site resources and the cropping pattern. An economic evaluation should be conducted prior to installation to assure a worthwhile investment.

This Guide will assist planners and irrigators with the development and implementation of effective irrigation water management plans.

Chapter 2 Soils

Contents **NJ652.02**

Tables

NJ652.02 Soils

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

Four factors require primary concern in choosing the method of water distribution and planning the irrigation system:

(1) Water holding capacity of the soil;
(2) Water intake rate of the soil;
(3) Root system characteristics of the crop to be irrigated; and,
(4) The amount of water required by a crop at various stages of growth.

This chapter examines the soil characteristics that must be considered in developing an effective and efficient irrigation system. Chapter 3 looks at crops and how they affect the irrigation system.

(a) Water holding capacity

The water holding capacity of a soil, and the plant's use rate, will determine irrigation frequency and the amount to be applied at each irrigation. The soil acts as a reservoir, and its water supply must be replenished often enough to keep water available for the plant's withdrawal as required for optimum growth and production.

Water holding capacity of any soil is determined by its texture, structure, and the amount of organic matter it contains. The first factor may be considered constant, while the latter two may be changed and modified by the farmer through various land preparation and cultivation practices.

Soil Texture - is the relative proportions of various sized particles in the profile.

Soil Structure - is the manner in which the different sizes of mineral particles are arranged in groups and aggregated bodies within the growing depth of the soil.

Organic Matter – includes non-mineral substances that have been incorporated into the soil profile and will hold several times its weight in water.

All these factors determine the supply of water and air that can be held in a soil and the rate at which it can absorb water.

(b) Water Intake Rate

A soil's intake rate is the measure of its capacity to absorb water applied to the surface during the period of application and is determined by several factors and combinations of soil characteristics.

It is good to remember that the water intake rate of any soil can be changed by tillage practices and that it will differ from field to field, from irrigation to irrigation, and from season to season.

Generally, the amount of moisture taken in by the soil will be determined by its moisture content and structure.

Water will be taken in faster by a dry soil. The rate of intake slows as the soil profile approaches a condition of saturation.

If the soil profile is made up of layers having various textural characteristics, the intake rate will be determined by the horizon having the lowest water transmission rate, whether it be on the surface or in the lower part of the root zone.

Surface sealing, a breakdown in structure often caused by the beating action of raindrops or sprinkler drops, very often changes the intake rate. Water flowing over the surface and moving fine particles to the pores surrounding larger particles can also result in surface sealing.

Oftentimes tillage practices and use of heavy equipment on the land during the growing season will cause soil compaction, formation of a plow pan, and other conditions that change the soil's moisture absorbing ability. A buildup of salts in the soil will reduce the intake rate.

Refer to Table NJ 2.1 Soil Information for Design Purposes.

(c) Water Application Rates

The rate at which water is applied depends on the following:

a. The time required for the soil to absorb the calculated depth of application without runoff for the given conditions of soil, slope, and cover. The depth of application divided by this required time is the maximum application rate.

b. The minimum application rate that will result in reasonably uniform distribution and satisfactory efficiency under prevalent climatic conditions.

c. The desirable time for applying the required depth of water considering efficient use of available labor and the other operations on the farm.

d. The application rate adjusted to the number of operating sprinklers using the most practical layout of lateral and main lines.

In all cases, the selected water-application rate must fall somewhere between maximum and minimum values.

Table NJ 2.1 contains maximum water application rates for different soils and for clean tilled crops and sod or other close-grown crops. Actual water application rates should not exceed the maximum rates given in Table NJ 2.1.

With Center Pivot systems, application rates should not exceed soil intake rates unless soil surface storage or other considerations are made. To determine maximum application rates for center pivot and lateral move systems refer to Table NJ 2.2, Soil Intake Groups, and Table NJ 2.3, Maximum Sprinkler Application Rates.

For most overhead irrigated crops, the minimum practical rate of application to obtain reasonably good distribution and high efficiency is about 0.20 inch per hour under favorable climatic conditions. Where high temperatures and high wind velocities are common, the minimum application rate should be higher.

(d) Available Water Capacity (AWC)

Available water capacity is the soil moisture (water) that can be extracted and used by plants. It is essential to plant growth in absorbing and assimilating the plant food from the soil. Available water capacity (AWC) is the amount of water the soil holds between the upper limit, field capacity, and the lower limit, permanent wilting point.

Field Capacity is the soil moisture that exists when the maximum amount of water is held against gravity in the soil profile. It may take from two days to several weeks for all gravitational water to drain through the subsoil. For practical purposes, the field capacity of a well-drained soil can be taken as the moisture condition when the drainage losses from the root zone are minor. This will be from one to two days after full wetting, depending on soil texture. The soil water above field capacity is equally or more available to plants than that at or below field capacity. Plant roots will use some of this free water. The amount the plant will use depends upon the rapidity of drainage down to field capacity and the frequency of irrigations. Even though the physical characteristics of a soil to be irrigated have not been established by laboratory tests, the percentage of water at field capacity can be measured in the field (Refer to “Measuring Soil Water Content”, Chapter 9). These measurements should be made during the growing season on bare ground one or two days following a soaking rain, adequate irrigation, or other artificial wetting. If measurements are being attempted without the entire field soaked by rain or irrigation, consult a soil scientist for the proper procedure.

Permanent Wilting Point - is the soil moisture that exists when plants can no longer obtain sufficient moisture to satisfy transpiration requirements and the plants wilt and remains wilted.

The permanent wilting point is determined accurately by a laboratory measurement. Where the wilting percentage is not available for a given soil, it may be estimated by comparing the soil to be irrigated with a similar soil that has been characterized by laboratory procedures.

The available water capacity of the soil within the root zone can be determined by subtracting the amount of moisture remaining in the soil at the permanent wilting point from the amount held at field capacity. The total available water capacity will vary on the same soil for different plants, depending upon their rooting depth and characteristics. For irrigation water management, the total available water is calculated for a soil depth based on the rooting characteristics of the mature plant. Generally, free water is available to plants for about one to two days when soil moisture is above field capacity.

The depth to which the main body of the plant roots penetrates the soil in search of food and moisture determines the effective depth of the soil. This depth will influence the amount of water to be applied at each irrigation. Any restrictions in depth of soil which limit root growth, such as solid rock, an impervious clay layer, hardpan, low pH, gravel, coarse sand, or presence of a high water table, limit the effective soil depth. Soil pH lower than 5.5 is especially limiting to legumes such as alfalfa and soybeans. Table NJ 2.1 contains values for available water capacity for different soils and soil depth.

(e) Erosion Control

If the area under consideration is on sloping land, appropriate conservation measures are needed for protection against erosion and possible aggravation of the erosion hazard by irrigation.

(f) Information for Design Purposes

Table NJ 2.1 contains information on maximum application rates, available water capacity, and irrigation management needs of soils in New Jersey.

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

Column (2) - Maximum Application Rate - This column is subdivided to show, in inches per hour, the maximum safe sprinkler application rate for clean-tilled crops and for sod or other close-grown crops on flat lands. Rates shown assume flat land, good soil structure and soil management. If such conditions do not exist, application rates should be reduced accordingly. For slopes over 5%, rates should be reduced by at least 25%.

Column (3) - Total Available Water Capacity - This column shows, in inches, the total available water capacity normal for the soil series for the different depths of irrigation 6, 12, 18, and 24 inches. Depths less than 24 inches are given where there is a root restricting layer at less than 24 inches. 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.

Column (4) - Allowable Time Between Irrigations - These values were calculated on the assumptions that the design consumptive use is 0.2 inch per day and the available water capacity is allowed to be 50% depleted.

TABLE NJ 2.1 SOIL INFORMATION FOR DESIGN PURPOSES

(1) Soil Series	(2) Maximum Application Rate (Inches/Hour)		(3) Total Available Water Capacity (Inches)				(4) Allowable Time Between Irrigations (Days)			
	Clean Tilled	Sod or Close-Grown	Depth to be Irrigated				Depth to be Irrigated			
			6”	12”	18”	24”	6”	12”	18”	24”
Abbottstown	0.3	0.5	1.2	2.4	3.6	---	3	6	9	---
Adelphia	0.5	0.7	1.2	2.4.	3.6	4.8	3	6	9	12
Adrian	1.0	1.2	2.4	4.8	7.2	9.6	6	12	18	24
Alden	0.3	0.5	1.5	2.6	3.6	4.6	4	6	9	11
Alloway	0.4	0.6	1.1	2.1	3.3	4.4	3	5	8	11
Amwell	0.4	0.6	1.2	2.4	3.3	---	3	6	8	---
Annandale	0.5	0.7	0.9	1.8	2.7	3.6	2	4	7	9
Arendtsville	0.3	0.5	0.8	1.5	2.1	2.7	2	4	5	7
Arnot	0.2	0.4	1.0	1.6	2.1	---	2	4	5	---
Atherton	0.4	0.6	0.9	1.8	2.7	3.6	2	4	7	9
Athol	0.5	0.7	1.1	1.9	2.8	3.6	3	5	7	9
Atsion	1.0	1.2	0.4	0.8	1.2	1.8	1	2	3	4
Aura	0.4	0.6	0.8	1.7	2.5	3.4	2	4	6	8
Bartley	0.5	0.7	1.1	2.2	3.1	4.0	3	5	8	10
Bath	0.5	0.7	0.9	1.8	2.6	3.4	2	4	6	8
Bedington	0.5	0.7	0.8	1.6	2.4	3.2	2	4	6	8
Berks	0.5	0.7	0.6	1.2	1.6	2.0	1	3	4	5
Berryland	1.0	1.2	0.4	0.8	1.4	1.9	1	2	3	5
Biddeford	0.3	0.5	1.5	2.5	3.6	4.7	4	6	9	12
Bigapple	0.2	0.4	0.3	0.6	0.8	1.1	1	1	2	3
Birdsboro	0.4	0.6	1.0	2.0	3.0	4.0	2	5	7	10
Boonton	0.3	0.5	1.1	2.2	3.2	4.2	3	5	8	10
Bowmansville	0.4	0.6	1.1	2.2	3.2	4.3	3	5	8	11
Braceville	0.6	0.8	0.7	1.4	2.0	2.6	2	3	5	6
Broadkill	0.3	0.5	2.7	3.5	4.5	5.4	7	9	11	13
Bucks	0.4	0.6	1.3	2.6	3.8	5.0	3	6	9	12

TABLE NJ 2.1 SOIL INFORMATION FOR DESIGN PURPOSES (CONT.)

(1) 50ii Series	(2) Maximum Application Rate (Inches/Hour)		(3) Total Available Water Capacity (Inches)				(4) Allowable Time Between Irrigations (Days)			
	Clean Tilled	Sod or Close-Grown	Depth to be Irrigated				Depth to be Irrigated			
			6”	12”	18”	24”	6”	12”	18”	24”
Buddtown	0.3	0.5	1.1	2.1	3.3	4.3	3	5	8	11
Califon	0.5	0.7	1.3	2.5	3.6	4.4	3	6	9	11
Carlisle	0.5	0.7	2.4	4.8	7.2	9.6	6	12	18	24
Catden	0.1	0.3	2.4	4.7	7.2	9.6	6	12	18	24
Chalfont	0.4	0.6	1.2	2.2	3.1	3.8	3	5	8	9
Chatfield	0.2	0.4	1.7	2.4	3.2	4.0	4	6	8	10
Chenango	0.6	0.8	0.8	1.4	2.0	2.5	2	3	5	6
Chicone	0.4	0.6	1.3	2.1	3.0	3.8	3	5	8	10
Chillum	0.3	0.5	1.2	2.4	3.7	4.9	3	6	9	12
Chippewa	0.3	0.5	0.9	1.7	---	---	2	4	---	---
Cokesbury	0.4	0.6	1.3	2.7	4.0	5.0	3	7	10	12
Colemantown	0.4	0.6	1.3	2.6	3.9	5.2	3	6	to	13
Collington	0.6	0.8	0.9	1.8	2.7	3.8	2	4	7	9
Colonie	0.6	0.8	0.8	1.5	1.9	2.4	2	4	5	6
Colts Neck	0.7	0.9	1.0	1.9	2.8	3.7	2	5.	7	9
Croton	0.4	0.6	1.4	2.8	4.2	---	3	7	10	---
Delaware	0.3	0.5	1.1	2.2	3.0	3.9	3	5	7	10
Dennisville	0.3	0.5	0.7	1.3	1.9	2.5	2	3	5	6
Donlonton	0.4	0.6	1.0	2.0	3.3	4.6	2	5	8	11
Downer	0.7	0.9	0.8	1.6	2.3	3.1	2	4	6	8
Doylestown	0.4	0.6	0.9	1.7	2.5	3.2	2	4	6	8
Duffield	0.4	0.6	1.1	2.2	3.2	4.2	3	5	8	10
Dunellen	0.6	0.8	0.9	1.8	2.7	3.6	2	4	7	9
Edneyville	0.5	0.7	0.8	1.7	2.6	3.5	2	4	6	9
Elkton	0.3	0.5	1.1	2.2	3.2	4.2	3	5	8	10
Ellington	0.5	0.7	1.1	2.2	3.2	1.3	3	5	8	11
Evesboro	1.0	1.2	0.4	0.8	1.2	1.6	1	2	3	4

TABLE NJ 2.1 SOIL INFORMATION FOR DESIGN PURPOSES (CONT.)

(1) Soil Series	(2) Maximum Application Rate (inches/Hour)		(3) Total Available Water Capacity (Inches)				(4) Allowable Time Between Irrigations (Days)			
	Clean Tilled	Sod or Close-Grown	Depth to be Irrigated				Depth to be Irrigated			
			6”	12”	18”	24”	6”	12”	18”	24”
Fallsington	0.6	0.8	1.2	2.3	3.3	4.3	3	6	8	11
Farmington	0.3	0.5	1.2	1.9	2.2	2.2	3	5	6	6
Fort Mott	0.7	0.9	0.4	0.9	1.3	1.9	1	2	3	4
Fredon	0.6	0.8	1.0	1.9	2.9	3.8	2	5	7	9
Freehold	0.6	0.8	1.0	2.0	3.1	4.1	2	5	8	10
Galestown	1.0	1.2	0.4	0.8	1.3	1.7	1	2	3	4
Galloway	0.7	0.9	0.5	1.0	1.5	2.0	1	2	4	5
Galway	0.3	0.5	1.6	2.5	3.2	3.7	4	6	8	9
Glassboro	0.6	0.9	0.6	1.3	2.0	2.7	1	3	5	7
Haledon	0.3	0.5	1.1	2.2	3.2	4.2	3	5	8	10
Halsey	0.5	0.7	1.3	2.6	4.0	4.9	3	6	10	12
Hammonton	0.7	0.9	0.8	1.6	2.3	3.1	2	4	6	8
Hasbrouck	0.2	0.4	1.2	2.4	3.5	4.4	3	6	9	11
Hazen	0.5	0.7	1.0	1.9	2.6	3.3	2	5	6	8
Hazleton	0.6	0.8	0.8	1.4	2.0	2.6	2	3	5	6
Hero	0.6	0.8	1.1	2.2	3.3	4.3	3	5	8	11
Hibernia	0.4	0.6	0.8	1.6	2.3	3.1	2	4	6	8
Hinckley	0.2	0.4	0.5	1.0	1.4	1.7	1	2	3	4
Hollis	0.2	0.4	1.6	2.4	2.9	2.9	4	6	7	7
Holmdel	0.7	0.9	1.0	2.0	3.0	4.0	2	5	7	10
Holyoke	0.6	0.8	1.0	2.0	---	---	2	5	---	---
Hoosic	0.6	0.8	0.6	1.0	1.5	1.9	1	2	4	5
Horseneck	0.3	0.5	0.8	1.5	2.3	3.0	2	4	6	7
Howell	0.4	0.6	1.1	2.2	3.3	4.9	3	5	8	12
Humaquepts	0.3	0.5	0.7	1.4	2.2	2.9	2	3	5	7
Ingleside	0.5	0.7	0.8	1.6	2.6	3.6	2	4	6	9

TABLE NJ 2.1 SOIL INFORMATION FOR DESIGN PURPOSES (CONT.)

(1) Soil Series	(2) Maximum Application Rate (Inches/Hour)		(3) Total Available Water Capacity (inches)				(4) Allowable Time Between Irrigations (Days)			
	Clean Tilled	Sod or Close-Grown	Depth to be Irrigated				Depth to be Irrigated			
			6”	12”	18”	24”	6”	12”	18”	24”
Jade Run	0.5	0.7	1.3	2.6	3.9	4.9	3	6	10	12
Keansburg	0.4	0.6	1.4	2.7	4.0	5.2	3	7	10	13
Keyport	0.3	0.5	0.8	1.9	3.0	4.0	2	5	7	10
Klej	0.7	0.9	0.5	1.0	1.5	2.0	1	2	4	5
Klinesville	0.8	1.0	0.5	1.1	---	---	1	3	--	---
Knickerbocker	0.2	0.4	0.8	1.6	2.5	3.4	2	4	6	8
Kresson	0.7	0.9	1.0	2.0	3.0	4.1	2	5	7	10
Lackawanna	0.5	0.7	0.8	1.6	2.3	3.0	2	4	6	8
Lakehurst	1.0	1.2	0.4	0.8	1.2	1.6	1	2	3	4
Lakewood	1.0	1.2	0.4	0.8	1.2	1.6	1	2	3	4
Lamington	0.4	0.6	1.0	1.9	2.6	3.6	2	5	6	9
Lansdale	0.5	0.7	1.1	2.3	3.1	3.8	3	6	8	9
Lansdowne	0.4	0.6	1.4	2.7	3.8	4.9	3	7	9	12
Lawrenceville	0.4	0.6	1.2	2.3	3.2	4.2	3	6	8	10
Legore	0.7	0.9	1.0	2.0	3.1	4.1	2	5	8	10
Lehigh	0.4	0.6	1.1	2.1	3.1	4.0	3	5	8	10
Lenni	0.4	0.6	1.2	2.4	3.4	4.3	3	6	8	11
Lenior	0.4	0.6	1.0	1.9	2.7	3.6	2	5	7	9
Livingston	0.2	0.4	1.0	2.0	2.8	3.5	2	5	7	9
Lordstown	0.2	0.4	1.1	1.9	2.7	3.4	3	5	7	8
Lyons	0.4	0.6	1.2	2.5	3.3	4.0	3	6	8	10
Manahawkin	0.6	0.8	2.0	3.9	5.8	7.8	5	9	14	19
Manlius	0.3	0.5	0.8	1.5	2.2	2.6	2	4	5	6
Mannington	0.3	0.5	1.1	2.2	3.5	4.8	3	5	9	12
Marlton	0.5	0.7	1.1	2.3	3.4	4.5	3	6	8	11
Matapeake	0.4	0.6	1.2	2.4	3.6	4.9	3	6	9	12

TABLE NJ 2.1 SOIL INFORMATION FOR DESIGN PURPOSES (CONT.)

(1) Soil Series	(2) Maximum Application Rate (Inches/Hour)		(3) Total Available Water Capacity (Inches)				(4) Allowable Time Between Irrigations (Days)			
	Clean Tilled	Sod or Close-Grown	Depth to be Irrigated				Depth to be Irrigated			
			6”	12”	18”	24”	6”	12”	18”	24”
Matawan	0.5	0.7	0.7	1.4	2.2	2.9	2	3	5	7
Mattapex	0.4	0.6	1.1	2.2	3.2	4.4	3	5	8	11
Meckesville	0.3	0.5	0.9	1.8	2.6	3.5	2	4	6	9
Middlebury	0.5	0.7	1.0	1.9	2.8	3.7	2	5	7	9
Minoa	0.5	0.7	1.0	2.0	3.0	4.0	2	5	7	10
Mispillion	0.3	0.5	2.4	4.7	7.2	9.6	6	12	18	24
Mount Lucas	0.4	0.6	1.1	2.2	3.0	3.8	3	5	7	9
Mullica	0.5	0.7	0.9	1.9	2.8	3.8	2	5	7	9
Nanticoke	0.3	0.5	1.1	2.0	3.0	3.9	3	5	7	10
Nassau	0.5	0.7	0.7	1.3	---	---	2	3	---	---
Natchaug	0.1	0.3	2.4	4.7	7.2	9.6	6	12	18	24
Neshaminy	0.5	0.7	1.0	1.9	2.6	3.3	2	5	6	8
Netcong	0.5	0.7	0.8	1.6	2.4	3.2	2	4	6	8
Nixon	0.6	0.8	0.8	1.7	2.4	3.1	2	4	6	8
Norton	0.4	0.6	1.3	2.3	3.2	4.1	3	6	8	10
Norwich	0.4	0.6	1.0	1.9	2.5	3.0	2	5	6	7
Oquaga	0.5	0.7	0.7	1.1	1.6	2.1	2	3	4	5
Othello	0.4	0.6	1.2	2.3	3.4	4.4	3	6	8	11
Otisville	0.7	0.9	0.6	0.8	1.0	1.2	1	2	2	3
Palms	0.3	0.5	2.7	5.3	8.2	10.8	7	13	20	27
Palmyra	0.4	0.6	0.9	1.7	2.4	3.0	2	4	6	7
Parker	0.8	1.0	0.7	1.4	2.2	2.9	2	3	5	7
Parsippany	0.3	0.5	1.2	2.3	3.2	4.2	3	6	8	10
Pascack	0.4	0.6	1.0	1.7	2.6	3.3	2	4	6	8
Passaic	0.4	0.6	1.2	2.3	3.3	4.2	3	6	8	10
Pattenburg	0.5	0.7	1.0	2.0	2.9	3.8	2	5	7	9

TABLE NJ 2.1 SOIL INFORMATION FOR DESIGN PURPOSES (CONT.)

(1) Soil Series	(2) Maximum Application Rate (Inches/Hour)		(3) Total Available Water Capacity (Inches)				(4) Allowable Time Between Irrigations (Days)			
	Clean Tilled	Sod or Close Grown	Depth to be Irrigated				Depth to be Irrigated			
			6”	12”	18”	24”	6”	12”	18”	24”
Pawcatuck	0.3	0.5	1.6	3.2	4.9	6.5	4	8	12	16
Paxton	0.2	0.4	0.8	1.5	2.4	3.1	2	4	6	8
Peckmantown	0.3	0.5	1.2	2.4	3.4	4.2	3	6	8	11
Pedricktown	0.3	0.5	1.9	2.9	3.7	4.3	5	7	9	11
Pemberton	0.8	1.0	0.4	0.8	1.3	1.7	1	2	3	4
Penn	0.4	0.6	1.0	2.0	3.0	4.0	2	5	7	10
Phalanx	0.8	1.0	0.6	1.3	2.1	2.5	1	3	5	6
Plummer	0.7	0.9	0.3	0.7	1.0	1.3	1	2	2	3
Pompton	0.6	0.8	1.0	1.9	2.7	3.5	2	5	7	9
Pope	0.7	0.9	1.0	2.0	2.8	3.7	2	5	7	9
Portsmouth	0.4	0.6	0.9	1.8	2.8	3.7	2	4	7	9
Preakness	0.6	0.8	1.1	2.3	3.1	4.0	3	6	8	10
Psamments	0.2	0.4	0.2	0.5	0.7	1.0	0.5	1	2	2
Quakerbridge	0.1	0.3	1.0	1.4	1.8	2.2	2	3	4	5
Quakertown	0.4	0.6	1.3	2.6	3.7	4.8	3	6	9	12
Raritan	0.4	0.6	1.0	2.0	2.8	3.7	2	5	7	9
Raynham	0.3	0.5	1.5	2.8	4.1	5.5	4	7	10	14
Readington	0.4	0.6	1.0	1.9	2.5	3.2	2	5	6	8
Reaville	0.4	0.6.	1.0	1.9	2.5	3.0	2	5	6	7
Ridgebury	0.4	0.6	0.8	1.6	2.2	2.6	2	4	5	6
Riker	0.2	0.4	0.4	0.8	1.3	1.6	1	2	3	4
Riverhead	0.6	0.9	0.9	1.7	2.4	3.1	2	4	6	8
Rockaway	0.5	0.7	0.9	1.7	2.5	3.2	2	4	6	8
Rowland	0.4	0.6	1.0	1.9	2.9	3.8	2	5	7	9
Royce	0.4	0.6	1.2	2.4	3.6	4.8	3	6	9	12
Sassafras	0.5	0.7	0.8	1.6	2.6	3.6	2	4	6	9

TABLE NJ 2.1 SOIL INFORMATION FOR DESIGN PURPOSES (CONT.)

(1) Soil Series	(2) Maximum Application Rate (Inches/Hour)		(3) Total Available Water Capacity (Inches)				(4) Allowable Time Between Irrigations (Days)			
	Clean Tilled	Sod or Close Grown	Depth to be Irrigated 6”	12”	18”	24”	Depth to be Irrigated 6”	12”	18”	24”
Scio	0.5	0.7	1.2	2.4	3.6	4.7	3	6	9	12
Sharptown	0.4	0.6	1.2	2.3	3.5	4.5	3	6	9	11
Shrewsbury	0.6	0.8	1.3	2.5	3.7	4.9	3	6	9	12
Steinsburg	0.5	0.7	0.7	1.4	2.0	2.3	2	3	5	6
Swainton	0.3	0.5	0.9	1.6	2.3	3.0	2	4	6	7
Swartswood	0.6	0.8	0.6	1.2	1.8	2.4	1	3	4	6
Swedesboro	0.2	0.4	0.4	0.9	1.8	2.5	1	2	4	6
Tinton	0.7	0.9	0.4	0.8	1.3	1.7	1	2	3	4
Tioga	0.5	0.7	1.0	1.8	2.6	3.4	2	4	6	8
Transquaking	0.1	0.3	2.7	5.3	8.2	10.8	7	13	20	27
Trussum	0.4	0.6	1.2	2.5	3.8	5.0	3	6	9	12
Tunkhannock	0.2	0.4	0.7	1.3	1.9	2.5	2	3	5	6
Turbotville	0.5	0.7	1.2	2.3	3.4	4.2	3	6	8	10
Unadilla	0.6	0.8	1.2	2.3	3.4	4.6	3	6	8	11
Venango	0.3	0.5	1.1	2.2	3.2	3.7	3	5	8	9
Wallkill	0.5	0.7	1.0	2.0	3.1	4.1	2	5	8	10
Wallpack	0.4	0.6	1.0	1.8	2.5	3.1	2	4	6	8
Washington	0.5	0.7	1.1	2.2	3.3	4.4	3	5	a	11
Wassaic	0.5	0.7	0.9	1.7	2.6	3.4	2	4	6	8
Watchung	0.4	0.6	1.0	2.0	2.9	3.8	2	5	7	9
Wayland	0.4	0.6	1.2	2.3	3.4	4.5	3	6	8	11
Weeksville	0.5	0.7	1.3	2.6	4.0	5.3	3	6	10	13
Wellsboro	0.2	0.4	2.4	3.7	4.5	5.2	6	9	11	13
Westphalia	0.5	0.7	1.1	2.1	3.1	4.1	3	5	8	10
Wethersfield	0.3	0.5	0.9	1.9	2.9	3.8	2	5	7	9
Whippany	0.4	0.6	1.3	2.5	3.5	4.6	3	6	9	11

TABLE NJ 2.1 SOIL INFORMATION FOR DESIGN PURPOSES (CONT.)

(1) Soil Series	(2) Maximum Application Rate (Inches/Hour)		(3) Total Available Water Capacity (Inches)				(4) Allowable Time Between Irrigations (Days)			
	Clean Tilled	Sod or Close Grown	Depth to be Irrigated				Depth to be Irrigated			
			6”	12”	18”	24”	6”	12”	18”	24”
Whitman	0.5	0.7	1.0	2.0	2.7	3.3	2	5	7	8
Willette	0.3	0.5	2.7	5.3	8.2	10.8	7	13	20	27
Woodmansie	1.0	1.2	0.4	0.8	1.4	2.1	1	2	3	5
Woodstown	0.6	0.8	0.9	1.8	2.7	3.7	2	4	7	9
Woodster	0.4	0.6	1.1	2.2	3.2	4.1	3	5	8	10
Wurtsboro	0.4	0.6	0.8	1.6	2.3	3.0	2	4	6	7
Yalesville	0.3	0.5	1.2	2.1	3.0	3.8	3	5	7	9

Table NJ 2.2 Soil Intake Groups

Soil Texture	NRCS Intake Family
Coarse Sand, Sand, Fine Sand Loamy Sand, Loamy Coarse Sand, Loamy Fine Sand, Loamy Very Fine Sand	1
Silt Loam, Fine Sandy Loam, Very Fine Loam, Loam	0.5
Silt Loam, Sandy Clay Loam, Clay Loam, Silty Clay Loam	0.3
Sandy Clay, Silty Clay, Clay	0.1

Table NJ 2.3 Maximum sprinkler application rate (Inches/Hour)
For 2000# Actual Residue at Planting

NRCS Intake Family	Design Slope Group	Maximum Application per Revolution 0.5	0.75	1	1.25
		Net Irrigation Application (Inches)			
1	0-1	4.8	4.8	4.8	4.8
	1.1-3	4.8	4.8	4.6	3.7
	3.1-5	4.8	3.2	3.2	2.8
	>5	3.1	2.6	2.2	2.1
.5	0-1	4.8	4.8	4.2	3.0
	1.1-3	4.8	3.6	2.5	2.0
	3.1-5	2.8	1.9	1.5	1.2
	>5	1.8	1.4	1.1	1.0
.3	0-1	4.8	4.8	3.0	1.8
	1.1-3	4.8	2.4	1.5	1.2
	3.1-5	1.9	1.1	0.9	0.7
	>5	1.2	0.8	0.6	0.6
.1	0-1	4.8	3.0	1.0	0.6
	1.1-3	4.8	0.8	0.5	0.4

Application rate adjustment for residue other than 2000#

With >4000# residue use 125% of above rate
With 4000# residue use 120% of above rate
With 3500# residue use 115% of above rate
With 3000# residue use 110% of above rate
With 2500# residue use 105% of above rate
With 1500# residue use 95% of above rate
With 1000# residue use 90% of above rate
With <1000# residue use 85% of above rate

Chapter 3 Crops

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NJ652.03 Crops

The primary crops irrigated in New Jersey are vegetables, sweet corn, melons, blueberries, cranberries, brambles, grapes, tree fruit, nursery stock, and turfgrass. Field corn, soybeans, hay and small grain are also irrigated.

(a) Critical Growth Periods

Aside from moisture needs to ensure a stand, most crops have critical periods during the growing season when good soil moisture 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 sufficient growing season exists for the desired development of the crop, short periods of low moisture during the early part of the growing season may not be harmful except for leaf or forage crops. However, over stimulation of vegetative growth from a combination of high soil fertility and available soil moisture can also be objectionable. This may delay time of harvest enough to miss the period of highest fresh market demand, affect the grade for processing, or cause losses in late maturing crops from frost damage. If irrigation water supplies are limited, the best use of the irrigation water supply would be during the critical growth period of the crop.

Table NJ 3.1 CRITICAL PERIODS OF WATER NEEDS FOR CROPS

Crop		Critical Periods
Asparagus		Crown set and transplanting
Alfalfa		Start of flowering and after cutting
Apples		Bud stage, fruit enlargement, and pre-harvest period.
Beans, lima		No particular period
Beans, snap		Pod enlargement
Blueberries		Bloom through fruit sizing
Brambles	Raspberries Blackberries	Blossom through harvest
Broccoli		Head formation and enlargement
Corn, sweet and field		Tasseling, silking, and early stage of ear development
Cabbage		Head development
Carrots		Root Enlargement
Cauliflower		Entire growing season
Cranberries		Spring and fall frost protection; Blossom through fruit sizing
Cucumbers		Flowering and fruit development
Eggplant		Flowering and fruit development
Grapes		Blossom to beginning stages of fruit ripening
Greens		Continuous
Lettuce		Head development
Melons		Flowering and fruit development
Onions		Bulb enlargement

Pasture		During establishment and boot stage to head development. Maintain MAD < 50%. Moisture stress immediately after grazing encourages fast regrowth.
Peaches		Final fruit enlargement and pit hardening
Peas		Flowering and seed enlargement
Peppers		Flowering, fruit development, fast enlarging stage
Potatoes	White	Tuber set and tuber enlargement
Potatoes	Sweet	Root enlargement
Pumpkins		Fruit stage
Radish		Root enlargement
Small grain		Boot, bloom, milk, early head development and ripening stages
Soybeans		Flowering and fruiting stage
Squash		Bud development and flowering
Strawberries		Fruit development through harvest
Tomatoes		Early flowering, fruit set and enlargement
Turnips		Root Enlargement

(b) Salinity Tolerance

High levels of salt accumulation in the root zone of the soil may affect plant growth in several ways.

First, it decreases the availability of nutrients and water for easy and rapid uptake by plant roots. This could lead to the need for more frequent irrigation on "salty" soils even though less than 50 percent of the normally available water has been used in the root zone. Such plants are usually stunted and have a bluish-green color.

Second, plants may be affected by a direct toxicity of one or more of the constituents of the salt in the irrigation water. These more frequently affect tree fruit than field or vegetable crops.

Third, after a certain amount of sodium has been absorbed on the clay particles, the soil tends to puddle very easily, becomes less permeable to air and water, and forms into hard lumps and crusts when dry. When and if this happens, the grower should consult Rutgers Cooperative Extension for powdered gypsum application rates, to counteract the excess sodium in the soil.

In Table NJ 3.2, different vegetable, fruit, and field crops are grouped according to their salt tolerances. Table NJ 3.3 shows the number of permissible irrigations with salt water between leaching rains for crops of different salt tolerances. The number of irrigations permitted should be decreased on heavier soils (silt and clay loams). If there is any evidence of severe leaf burning after one or two irrigations owing to excessive salt accumulation on the plant leaves, no more irrigations should be applied unless the failure to irrigate would result in greater loss than that due to burning of the crop.

TABLE NJ 3.2 SALT TOLERANCE OF PLANTS [1/]

Plants that can tolerate [2/]		
Up to 8-16 Millimhos [3/] 5120 to 10,240 ppm (Good Resistance)	Only up to 4-8 millimhos [3/] 2560 to 5120 ppm (Moderate Resistance)	No more than 1-4 millimhos [3/] 640 to 2560 ppm (Poor Resistance)
FIELD CROPS		
Barley and rape	Rye, wheat, oats, sorghum, corn, soybeans, and sorghum (grain)	Field beans
FORAGE CROPS		
Bermudagrass and barley hay	Sweet clover, sorghum, sudangrass, alfalfa, tall fescue, wheat and oat hays, orchardgrass perennial ryegrass, vetch, smooth brome, soybeans, Proso millet, pearl millet, and Alsike clover	White clover, Ladino clover, and red clover
VEGETABLE CROPS		
Garden beets, kale, asparagus, and spinach	Tomatoes, broccoli, cabbage, peppers, cauliflower, lettuce, sweet corn, potatoes, carrots, onions, peas, squash, cucumbers, collards, radishes, and rhubarb	Radishes, celery, and green beans
FRUIT CROPS		
	Grapes, cantaloupe	Pears, apples, plums, peaches
OTHER CROPS		
Bermudagrass, Zoysia, creeping bentgrass American beachgrass (production of)		Red fescue, Ky. bluegrass, colonial bentgrass

1/ The information in this table was obtained from USDA Agricultural Research Service Publication ARS41-29, "Brackish Water for Irrigation in Humid Regions" 1960.
2/ Crops plants listed in order of increasing sensitivity.
3/ These figures represent the electrical conductivity (ECe) of the soil saturation extract, where 1 millimho equals approx. 640 ppm of salts.

TABLE NJ 3.3 PERMISSIBLE NUMBER OF IRRIGATIONS WITH BRACKISH WATER BETWEEN LEACHING RAINS FOR CROPS OF DIFFERENT SALT TOLERANCES [1/]

Irrigation Water		Irrigations for Crops Having		
Total Salts	Electrical Conductivity	Good Salt Tolerance	Moderate Salt Tolerance	Poor Salt Tolerance
ppm	millimhos per cm at 25° C			
640	1		15	7
1280	2	11	7	4
1920	3	7	5	2
2560	4	5	3	2
3200	5	4	2-3	1
3840	6	3	2	1
4480	7	2-3	1-2	
5120	8	2	1	

1/ The information in this table was obtained from USDA Agriculture Information Bulletins Nos. 213 and 283.

(c) Irrigation-Related Management Factors

Management-Allowed Depletion Levels

It is essential to maintain available moisture in the soil within certain limits for good crop growth. The depletion of soil moisture by the crops must be limited to some level well above the wilting point, otherwise loss of production or permanent damage will result. Due to the time required to complete one irrigation, the application of water should be started in sufficient time to cover the entire field or fields before the soil moisture has reached the minimum allowed level in the last area to be irrigated. Crop growth is badly retarded after 75 to 80 percent of available moisture in the zone is depleted. For the purposes of both design and operation of sprinkler irrigation systems, this is the maximum allowed moisture depletion for most crops. Special crops, such as vegetables, potatoes, and strawberries, require that higher moisture levels be maintained. Trickle irrigation systems are usually designed to keep root zone moisture close to optimum level by daily applications. With drip irrigation systems, irrigate when 20% -25% of the available water in the active root zone is depleted.

The moisture level at which to start irrigation must be determined from a practical standpoint. Monitoring soil moisture depletion in the root zone is essential for determining when to irrigate. The irrigator generally is reluctant to start irrigation at too high a moisture level because the soil does not seem dry enough to warrant the trouble and labor of adding more water. As the moisture level is lowered by the delayed start and comes closer to the lower moisture limit, the allowed time to cover the field is lessened. The cost of an irrigation system designed to cover an area in a shorter period of time, particularly a sprinkler system, increases as the application time is reduced. Considering these factors, the logical level of available moisture at which to start irrigation, (with an overhead system) is when about 50 percent of the total available moisture has been depleted.

Rooting Depths (water extraction depth)

The effective root zone depth is the depth of soil used by the main body of the plant roots to obtain most of the stored moisture and plant food under proper irrigation. It is not the same as the maximum root zone depth. As a rule of thumb about 70% of the moisture extracted by the root is obtained in the top half of the root zone; about 20% from the third quarter; and about 10% from the soil in the deepest quarter of the root zone.

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

Application of irrigation water should be limited to an amount that will penetrate only to the effective root zone depth. Applications in excess of this amount will result in waste of water and added pumping cost. Also, in the lighter textured soils, heavy applications may cause leaching of plant food beyond reach of the plant feeder roots. Effective root zone depth for most of the irrigated crops is shown in Table NJ 3.4. These are generalized values for most crops and soils. The listed depths are generally satisfactory for management purposes. There may be occasions where field conditions indicate that effective root zone depth other than those listed may be more appropriate. The proper effective root zone depth can be determined in the field by observation and measurement. If moisture conditions and growth period have been sufficient to develop normal rooting characteristics, the effective root zone depth may be determined by digging a hole alongside the plant and carefully tunneling back underneath the plant to expose the hair like moisture feeder roots. The depth to which two or more rootlets are noted per six square inches of exposure indicates effective moisture utilization. Determination of the moisture content of each layer encountered will also show the moisture extraction pattern.

TABLE NJ 3.4 Effective Root Zone Moisture Extraction Depth in Unrestricted Soils (Top 50% of the root zone).

Truck Crops	**Effective Root Zone Depth (Inches)**	**Truck Crops**	**Effective Root Zone Depth (Inches)**
Asparagus	36	Lima beans	24
Beets	18	Melons	24
Broccoli	18	Okra	18
Cabbage	18	Onions - bunch	6
Carrots	18	Onions - dry	12
Cauliflower	18	Parsnips	24
Celery	12	Peas	18
Chives	6	Peppers	18
Collards	18	Potatoes	18
Corn (sweet)	24	Pumpkins	24
Cucumbers	18	Radish	6
Dandelion	6	Rutabagas	18
Eggplant	18	Shallots	12
Endive	6	Snap beans	18
Escarole	6	Spinach	6
Fennel	6	Squash	24
Horseradish	18	Sweet Potatoes	18
Kale	18	Swiss chard	12
Kohlrabi	18	Tomatoes	24
Lettuce	6	Turnips	18
		Watermelons	24
Field Crops and Grain	**Effective Root Zone Depth (Inches)**	**Fruits, Berries, and Orchards**	**Effective Root Zone Depth (Inches)**
Barley	24	Apples	30
Corn (field)	24	Blueberries*	30*
Millet	24	Cane fruits	24
Oats	24	Cranberries	6
Rye	24	Grapes	36
Sorghum	24	Peaches	24
Soybeans	24	Pears	24
Wheat	24	Strawberries	6
Grasses and Legumes	**Effective Root Zone Depth (Inches)**	**Grasses and Legumes**	**Effective Root Zone Depth (Inches)**
Alfalfa	36	Reed canarygrass	24
Bluegrass	18	Red clover	18
Bromegrass	24	Sudan grass	24
Ladino clover	18	Sweet clover	24
Orchardgrass	24		

*For Water Table Restrictions in Blueberries use 18” depth.

TABLE NJ 3.4 (CONT.)

Flowers	**Effective Root Zone in Inches**
Annual Flowers	6
Ericaceous ornamental plants (azalea, etc.)	12
Gladioli, peonies, iris	12
Other bulb or corm plants	12
Nursery Plants	**Effective Root Zone in Inches**
Bedded plants after propagation,	6
Finished landscape plants	18 to 24
Ground cover plants (vinca, ivy)	6
Lining-out plants	12
Perennial ornamentals - trees and shrubs (conifers and flowering shrubs)	24
Turf	**Effective Root Zone in Inches**
Athletic fields - in active use	6
Athletic fields - not in active use	12
Golf greens (bentgrass)	6
Golf fairways (bluegrass, fescue, zoysia, Bermuda grass)	6
Grass sod - being established or being prepared for immediate sale	6
Grass sod (lawns, sod being held for sale)	12

Each crop was given an effective depth based on:

1. Depth of soil to which the larger proportion of the total root system has developed when the marketable part of the crop is being produced or when the loss of water from turf and ornamental plants is greatest.

2. Research and experience regarding the overall water needs of each crop for maximum quality as well as yield or growth.

3. The kind of soil in which some crops, such as blueberries, Bermuda grass, and sweet potatoes, are commonly grown in New Jersey.

Note: Depth of irrigation while the crop is developing its root system should be determined by the actual depth to which roots have grown.

Chapter 4 Water Requirements

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NJ652.04 Water Requirements

(a) Crop Evapotranspiration, ETc

Plants must have a continuous supply of readily available moisture in order to maintain rapid, vigorous growth. The moisture used by plants plus the moisture evaporated directly from the field surface is called consumptive use, or evapotranspiration. The amount of moisture consumptively used in an irrigated field on any given day is related to the air temperature, the number of daylight hours, the crop, and the stage of growth of the crop. Other factors, such as wind speed, solar radiation, and relative humidity, also affect consumptive use rates. All crops have relatively low consumptive use rates when they are young. Their highest rates usually occur as they approach the stage of maximum vegetative development. For comparable stages of crop growth, consumptive use rates are greater on long, hot summer days than on short, cool spring or fall days.

Seasonal Consumptive Use
In New Jersey Seasonal Consumptive Use tables were developed using the Natural Resources Conservation Service Technical Release 21 and Software Program Irrigation Water Requirements, (modified Blaney Criddle method). This was calculated for each zone in New Jersey, (North, Central, and South), based on averaging crop water requirements developed from each station in each zone. Refer to Tables NJ 4.1, Net Irrigation Water Requirements, North, Central and South Jersey. Also the South Jersey RC&D Weather Station Network in southern and central NJ is available for use. This internet based system offers an on line irrigation scheduling program and calculates daily and monthly ET rates using the Penman-Monteith method and real time weather data.

Peak-Period Consumptive Use
The average daily water-use rate during the 6 to 10 days of the highest consumptive use of the season is called the peak-period use rate and is the design rate to be used in planning an irrigation system. The peak-use period generally occurs when the crop is starting to produce its harvest, vegetation is most abundant, and temperatures are high. In New Jersey, the following can be used for planning and design: Peak ETc crop tables developed for each New Jersey Zone using the NRCS Irrigation Water Requirement program (Refer to Tables NJ 4.2, Crop Consumptive Use and Peak ET); 0.2 inch per day for estimated average peak ET; or the South Jersey RC&D Weather Station Network for real time ET data and irrigation scheduling.

The peak-use period for various crops in a given area may occur at different times in the growing season. Early-maturing crops have their peak-use period in late spring or early summer and late-maturing crops, in late summer or early fall. Knowing when these peaks occur is important in working out a cropping plan in which the peak-use periods are staggered, thus reducing the total capacity requirement of the irrigation system. Refer to Table NJ 4.2, for peak water use month and Table NJ 4.3 Crop Coefficients for Growing Season. Crop coefficients (Kc) are highest at peak growth period and are used to calculate crop consumptive use (ETc), and net irrigation water requirements. ET x Kc = ETc

Crop Planting and Harvest Dates
Crop planting and harvest dates were determined by using information obtained by local growers, Rutgers and Penn State Cooperative Extension Production Guides. Refer to Table NJ 4.3.

Climate Data

The 1961 – 1990 NOAA Climatological Summary was used with NRCS TR 21 and NRCS Irrigation Water Requirements Software Program for calculating Effective Rainfall, Crop ET Rates and Net Irrigation Water Requirement data. Effective rainfall is the amount of precipitation that infiltrates into the root zone and is used by the plant. This was calculated using both the Normal Year (50% Chance) and Dry Year (80% Chance). The 80 percent chance rainfall, that which can be expected to be equaled or exceeded in 8 out of 10 years is normally used to determine crop irrigation requirements. Irrigation based on 80 percent chance rainfall is safer, and there is less risk of drought for the crop than if based on average years.

Climate includes several factors that affect the consumptive water requirements of crops. Therefore, three zones were established in NJ, for use in this guide, (North, South, and Central), Refer to Figure NJ 4.1, Irrigation Zones in New Jersey.

(b) Net Irrigation Water Requirements

The net irrigation water requirement is defined as the water required by irrigation to satisfy crop evapotranspiration and auxiliary water needs (leaching, temperature modification, crop quality), that are not provided by water stored in the soil profile or precipitation. The data furnished included rainfall records for each zone, (North, South, and Central) during a 30 year period, and “carryover” moisture accumulation in the soil profile during the non-growing season. Soil moisture “carryover” was estimated to be 1” for all zones. For crops grown on heavier texture soil the “carryover” can be increased to 2”. However the tables are created using a 1” moisture accumulation. Refer to Table NJ 4.1 for Net Irrigation Water Requirements.

Irrigation systems must be sized to meet peak period consumptive use. Peak daily evapotranspiration rates are used for a 22 hour irrigation period for planning and designing irrigation system flow rates. The system efficiency must also be factored in for gross irrigation water requirements. For potential application efficiencies for various irrigation systems and management practices, refer to Table NJ 4.4, Suggested Before (Eb) and After (Ea) System Efficiencies.

To calculate minimum pumping capacity required, use the following formula:

$$Q = \frac{453 \times DA}{T}$$

Where: Q = flow rate, gpm
T = time, hours
D = depth, inches (gross crop ET)
A = area, acres

These values are used when planning an irrigation water source. The minimum design capacity must meet the peak-period consumptive use requirements. If the water source has insufficient capacity, a reservoir may be needed to store the peak-period consumptive use requirements. The seasonal or monthly consumptive use values allow the needed storage size to be determined when the pumping rate of the well is known, the recharge rate of a ground water recharge pit is known, the low flow rate of a stream is known, or the annual water-yield of a watershed is known.

TABLE NJ 4.1a
NET IRRIGATION WATER REQUIRMENT (INCHES)
NORTH JERSEY

Crop Name	Dry Year Net Irrigation Requirements	Normal Year Net Irrigation Requirements
Alfalfa Hay	14.06	12.30
Apple, clean cultivated	10.49	8.76
Apples, with cover	16.60	14.81
Asparagus	4.32	3.54
Azalea/shrubs	14.77	13.04
Barley	6.17	5.08
Beans, snap	7.57	6.33
Beets	3.82	3.15
Blueberries	15.50	13.66
Broccoli	5.13	4.17
Cabbage	9.28	8.02
Carrots	9.63	8.41
Cauliflower	4.77	3.82
Celery	11.96	10.36
Collards,Kale, Broccoli Rabe (fall)	3.38	2.67
Collards,Kale, Broccoli Rabe (spring)	4.39	3.75
Corn, Grain	13.20	11.67
Cranberries	15.89	13.96
Cucumbers	8.50	7.32
Dandelion	2.53	1.95
Dry beans	8.35	7.38
Egg plant	7.78	6.50
Endive,Escarole, Lettuces (fall)	0.95	0.42
Endive,Escarole, Lettuces (spring)	2.19	1.67
Fennel	1.16	0.58
Grapes, Mature no cover 25% canopy	2.47	1.30
Grapes, Mature no cover 50% canopy	8.51	7.07
Grapes,1-2year; cover;10% canopy	0.60	0.00
Grapes,1-2year;no cover;10% canopy	0.34	0.00
Grapes,Mature; cover;25% canopy	5.00	3.68
Grapes,Mature; cover;50% canopy	11.00	9.48

Crop Name	Dry Year Net Irrigation Requirements	Normal Year Net Irrigation Requirements
Grass Hay	13.98	12.17
Green Beans	6.05	5.20
Lima beans	7.77	6.50
Melons	9.64	8.31
Onion/Scallions (early)	1.90	1.41
Onions (late)	7.02	6.08
Pasture (grass)	13.98	12.17
Peaches	14.15	12.29
Pears	14.15	12.29
Peas (early)	2.81	2.26
Peas (late)	2.74	2.18
Peppers	6.45	5.45
Potatoes (fall)	9.96	8.57
Potatoes, (summer)	12.10	10.67
Pumpkins	6.19	5.06
Radish (early spring)	0.23	0.02
Radishes (late spring)	1.00	0.71
Radishes (late summer)	0.98	0.61
Rasberries	14.46	12.73
Sorghum (silage)	8.00	6.58
Soybeans	7.67	6.47
Spinach (early)	1.47	1.01
Spinach (late)	1.63	1.22
Spring Oats	7.10	6.05
Squash (summer)	6.93	5.91
Strawberries	2.40	1.69
Sugar beet	14.00	12.58
Sweet Corn (2nd planting)	6.50	5.71
Sweet Corn (3rd planting)	6.96	6.07
Sweet Corn (early)	5.41	4.60
Sweet Potatoes	10.53	9.13
Tomatoes	11.04	9.67
Watermelons	9.99	8.67
Winter wheat	5.74	4.62

Reference:
NRCS, Irrigation Water Requirements Software Program; NEH Chapter 2, Irrigation Water Requirements.
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TABLE NJ 4.1b
NET IRRIGATION WATER REQUIRMENT (INCHES)
CENTRAL JERSEY

Crop Name	Dry Year Net Irrigation Requirements	Normal Year Net Irrigation Requirements
Alfalfa Hay	16.74	14.96
Apple, clean cultivated	12.87	11.12
Apples, with cover	19.61	17.82
Asparagus	5.60	4.84
Azalea/shrubs	17.63	15.89
Barley	6.94	6.03
Beans, snap	9.20	7.91
Beets	5.08	4.45
Blueberries	18.55	16.71
Broccoli	6.29	5.29
Cabbage	10.89	9.58
Carrots	11.26	10.00
Cauliflower	5.90	4.91
Celery	14.43	12.80
Collards,Kale, Broccoli Rabe (fall)	4.28	3.54
Collards,Kale, Broccoli Rabe (spring)	5.27	4.62
Corn, Grain	15.33	13.73
Cranberries	18.79	16.81
Cucumbers	10.04	8.83
Dandelion	3.60	3.07
Dry beans	9.66	8.67
Egg plant	9.43	8.13
Endive,Escarole, Lettuces (fall)	1.27	0.73
Endive,Escarole, Lettuces (spring)	3.14	2.64
Fennel	1.52	0.89
Grapes, Mature no cover 25% canopy	3.58	2.31
Grapes, Mature no cover 50% canopy	10.33	8.86
Grapes,1-2year; cover;10% canopy	0.80	0.00
Grapes,1-2year; no cover;10% canopy	0.46	0.00
Grapes,Mature; cover;25% canopy	6.45	5.09
Grapes,Mature; cover;50% canopy	13.27	11.74

Crop Name	Dry Year Net Irrigation Requirements	Normal Year Net Irrigation Requirements
Grass Hay	17.09	15.28
Green Beans	7.55	6.73
Lima beans	9.42	8.13
Melons	11.38	10.03
Onion/Scallions (early)	2.52	2.05
Onions (late)	8.24	7.27
Pasture (grass)	17.09	15.28
Peaches	16.90	14.98
Pears	16.90	14.98
Peas (early)	3.88	3.35
Peas (late)	3.54	2.97
Peppers	7.63	6.59
Potatoes (fall)	11.94	10.53
Potatoes, (summer)	14.25	12.81
Pumpkins	7.72	6.56
Radish (early spring)	0.53	0.27
Radishes (late spring)	1.51	1.24
Radishes (late summer)	1.17	0.80
Rasberries	17.35	15.61
Sorghum (silage)	9.89	8.42
Soybeans	9.01	7.77
Spinach (early)	2.12	1.67
Spinach (late)	2.37	1.92
Spring Oats	8.79	7.76
Squash (summer)	8.17	7.11
Strawberries	3.53	2.83
Sugar beet	16.13	14.67
Sweet Corn (2nd planting)	7.60	6.78
Sweet Corn (3rd planting)	8.11	7.20
Sweet Corn (early)	6.82	6.02
Sweet Potatoes	12.21	10.79
Tomatoes	12.98	11.59
Watermelons	11.83	10.48
Winter wheat	8.20	7.17

Reference:
NRCS, Irrigation Water Requirements Software Program; NEH Chapter 2, Irrigation Water Requirements.

TABLE NJ 4.1c
NET IRRIGATION WATER REQUIRMENT (INCHES)
SOUTH JERSEY

Crop Name	Dry Year Net Irrigation Requirements	Normal Year Net Irrigation Requirements
Alfalfa Hay	18.96	17.25
Apple, clean cultivated	14.87	13.16
Apples, with cover	22.00	20.27
Asparagus	5.80	5.01
Azalea/shrubs	19.90	18.24
Barley	7.29	6.38
Beans, snap	10.76	9.56
Beets	5.59	4.96
Blueberries	20.45	18.67
Broccoli	7.44	6.49
Cabbage	12.45	11.21
Carrots	12.89	11.68
Cauliflower	7.30	6.38
Celery	16.55	14.97
Collards,Kale, Broccoli Rabe (fall)	5.28	4.59
Collards,Kale, Broccoli Rabe (spring)	5.87	5.22
Corn, Grain	17.42	15.87
Cranberries	21.07	19.12
Cucumbers	11.58	10.44
Dandelion	4.08	3.56
Dry beans	11.13	10.21
Egg plant	11.13	9.90
Endive,Escarole, Lettuces (fall)	1.96	1.47
Endive,Escarole, Lettuces (spring)	3.54	3.04
Fennel	3.36	2.68
Grapes, Mature no cover 25% canopy	4.87	3.66
Grapes, Mature no cover 50% canopy	12.19	10.81
Grapes,1-2year; cover;10% canopy	1.02	0.32
Grapes,1-2year; no cover;10%canopy	0.61	0.00
Grapes,Mature; cover;25% canopy	7.92	6.62
Grapes,Mature; cover;50% canopy	15.31	13.87

Crop Name	Dry Year Net Irrigation Requirements	Normal Year Net Irrigation Requirements
Grass Hay	19.39	17.67
Green Beans	8.31	7.49
Lima beans	11.12	9.89
Melons	13.12	11.87
Onion/Scallions (early)	2.88	2.40
Onions (late)	9.68	8.78
Pasture (grass)	19.63	17.79
Peaches	19.18	17.31
Pears	19.18	17.31
Peas (early)	4.31	3.78
Peas (late)	4.40	3.87
Peppers	9.74	8.69
Potatoes (fall)	13.84	12.50
Potatoes, (summer)	15.97	14.57
Pumpkins	9.27	8.16
Radish (early spring)	0.66	0.39
Radishes (late spring)	1.73	1.46
Radishes (late summer)	1.69	1.34
Rasberries	19.59	17.93
Sorghum (silage)	11.75	10.34
Soybeans	10.44	9.28
Spinach (early)	2.39	1.92
Spinach (late)	3.12	2.61
Spring Oats	9.86	8.85
Squash (summer)	9.47	8.47
Strawberries	4.01	3.30
Sugar beet	18.23	16.84
Sweet Corn (2nd planting)	8.51	7.72
Sweet Corn (3rd planting)	9.25	8.39
Sweet Corn (early)	7.63	6.85
Sweet Potatoes	13.97	12.64
Tomatoes	14.88	13.55
Watermelons	13.67	12.40
Winter wheat	9.18	8.16

Reference:
NRCS, Irrigation Water Requirements Software Program; NEH Chapter 2, Irrigation Water Requirements.

TABLE NJ 4.2a
CROP CONSUMPTIVE USE AND PEAK ET
NORTH JERSEY

Crop Name	Seasonal Consumptive use (inches)	Month	Peak ET
Alfalfa Hay	26.18	July	0.30
Apple, clean cultivated	22.44	July	0.24
Apples, with cover	28.90	July	0.31
Asparagus	9.73	June	0.17
Azalea/shrubs	26.75	July	0.28
Barley	14.27	June	0.18
Beans, snap	16.44	August	0.23
Beets	9.01	May	0.12
Blueberries	28.14	July	0.29
Broccoli	12.23	August	0.21
Cabbage	18.26	July	0.26
Carrots	18.40	July	0.27
Cauliflower	11.83	August	0.20
Celery	23.10	July	0.27
Collards,Kale, Broccoli Rabe (fall)	8.88	August	0.16
Collards,Kale, Broccoli Rabe (spring)	9.45	June	0.21
Corn, Grain	23.42	August	0.30
Cranberries	29.06	July	0.31
Cucumbers	16.97	July	0.25
Dandelion	6.65	June	0.15
Dry beans	15.45	July	0.26
Egg plant	16.80	August	0.23
Endive,Escarole, Lettuces (fall)	5.02	September	0.10
Endive,Escarole, Lettuces (spring)	6.51	May	0.14
Fennel	5.78	August	0.11
Grapes, Mature no cover 25% canopy	11.24	July	0.12
Grapes, Mature no cover 50% canopy	18.61	July	0.21
Grapes,1-2year; cover;10% canopy	7.13	July	0.07
Grapes,1-2year;no cover;10% canopy	5.56	July	0.06
Grapes,Mature; cover;25% canopy	14.39	July	0.16
Grapes,Mature; cover;50% canopy	21.65	July	0.25

Crop Name	Seasonal Consumptive use (inches)	Month	Peak ET
Grass Hay	26.51	July	0.26
Green Beans	12.36	June	0.25
Lima beans	16.79	August	0.23
Melons	19.00	July	0.29
Onion/Scallions (early)	5.79	May	0.10
Onions (late)	13.97	August	0.23
Pasture (grass)	26.51	July	0.26
Peaches	27.00	July	0.28
Pears	27.00	July	0.28
Peas (early)	7.36	May	0.13
Peas (late)	7.29	September	0.14
Peppers	13.82	July	0.22
Potatoes (fall)	19.76	August	0.26
Potatoes, (summer)	22.14	July	0.29
Pumpkins	14.40	August	0.21
Radish (early spring)	2.27	May	0.10
Radishes (late spring)	3.34	June	0.15
Radishes (late summer)	4.06	September	0.11
Rasberries	26.49	July	0.29
Sorghum (silage)	17.98	August	0.24
Soybeans	15.74	August	0.25
Spinach (early)	4.84	May	0.13
Spinach (late)	5.99	September	0.14
Spring Oats	14.73	June	0.24
Squash (summer)	14.42	July	0.24
Strawberries	7.88	June	0.16
Sugar beet	23.98	July	0.31
Sweet Corn (2nd planting)	12.57	June	0.19
Sweet Corn (3rd planting)	13.58	July	0.28
Sweet Corn (early)	11.63	June	0.23
Sweet Potatoes	19.94	July	0.26
Tomatoes	20.68	July	0.28
Watermelons	19.34	August	0.27
Winter wheat	14.12	June	0.21

Reference:
NRCS, Irrigation Water Requirements Software Program; NEH Chapter 2, Irrigation Water Requirements.

TABLE NJ 4.2b
CROP CONSUMPTIVE USE AND PEAK ET
CENTRAL NEW JERSEY

Crop Name	Seasonal Consumptive use (inches)	Month	Peak ET
Alfalfa Hay	28.55	July	0.31
Apple, clean cultivated	24.55	July	0.25
Apples, with cover	31.55	July	0.33
Asparagus	10.75	June	0.19
Azalea/shrubs	29.15	July	0.30
Barley	13.46	May	0.16
Beans, snap	18.07	August	0.25
Beets	9.90	May	0.13
Blueberries	30.74	July	0.31
Broccoli	13.35	August	0.22
Cabbage	19.77	July	0.28
Carrots	19.93	July	0.29
Cauliflower	12.91	August	0.21
Celery	25.32	July	0.29
Collards,Kale, Broccoli Rabe (fall)	9.78	August	0.17
Collards,Kale, Broccoli Rabe (spring)	10.24	June	0.22
Corn, Grain	25.56	August	0.32
Cranberries	31.81	July	0.33
Cucumbers	18.38	July	0.26
Dandelion	7.31	June	0.16
Dry beans	16.68	July	0.27
Egg plant	18.27	August	0.25
Endive,Escarole, Lettuces (fall)	5.51	September	0.09
Endive,Escarole, Lettuces (spring)	7.18	May	0.15
Fennel	6.31	August	0.11
Grapes, Mature no cover 25% canopy	12.23	July	0.13
Grapes, Mature no cover 50% canopy	20.26	July	0.22
Grapes,1-2year; cover;10% canopy	7.76	July	0.08
Grapes,1-2year; no cover;10% canopy	6.05	July	0.06
Grapes, Mature; cover;25% canopy	15.67	July	0.17
Grapes, Mature; cover;50% canopy	23.57	July	0.26

Crop Name	Seasonal Consumptive use (inches)	Month	Peak ET
Grass Hay	29.02	July	0.27
Green Beans	13.52	June	0.27
Lima beans	18.27	August	0.25
Melons	20.57	July	0.31
Onion/Scallions (early)	6.37	May	0.11
Onions (late)	15.12	August	0.25
Pasture (grass)	29.02	July	0.27
Peaches	29.58	July	0.30
Pears	29.58	July	0.30
Peas (early)	8.10	May	0.15
Peas (late)	8.03	September	0.15
Peppers	14.92	July	0.23
Potatoes (fall)	21.54	August	0.28
Potatoes, (summer)	24.02	July	0.31
Pumpkins	15.77	August	0.23
Radish (early spring)	2.57	May	0.11
Radishes (late spring)	3.65	June	0.16
Radishes (late summer)	4.46	September	0.12
Rasberries	28.91	July	0.31
Sorghum (silage)	19.78	August	0.26
Soybeans	17.13	August	0.27
Spinach (early)	5.39	May	0.14
Spinach (late)	6.67	September	0.15
Spring Oats	16.06	June	0.26
Squash (summer)	15.56	July	0.26
Strawberries	8.71	June	0.17
Sugar beet	26.02	August	0.33
Sweet Corn (2nd planting)	13.55	June	0.21
Sweet Corn (3rd planting)	14.61	July	0.30
Sweet Corn (early)	12.62	June	0.25
Sweet Potatoes	21.50	August	0.28
Tomatoes	22.48	July	0.29
Watermelons	21.00	August	0.30
Winter wheat	15.50	June	0.23

Reference:
NRCS, Irrigation Water Requirements Software Program; NEH Chapter 2, Irrigation Water Requirements.

TABLE NJ 4.2c
CROP CONSUMPTIVE USE AND PEAK ET
SOUTH JERSEY

Crop Name	Seasonal Consumptive use (inches)	Month	Peak ET
Alfalfa Hay	29.88	July	0.33
Apple, clean cultivated	25.71	July	0.26
Apples, with cover	33.00	July	0.35
Asparagus	11.14	June	0.20
Azalea/shrubs	30.45	July	0.32
Barley	13.51	May	0.18
Beans, snap	18.70	August	0.27
Beets	10.23	May	0.13
Blueberries	31.91	July	0.33
Broccoli	14.06	August	0.24
Cabbage	20.61	July	0.29
Carrots	20.84	July	0.31
Cauliflower	13.60	August	0.22
Celery	26.62	July	0.30
Collards,Kale, Broccoli Rabe (fall)	10.34	August	0.18
Collards,Kale, Broccoli Rabe (spring)	10.62	June	0.23
Corn, Grain	26.85	August	0.34
Cranberries	33.28	July	0.35
Cucumbers	19.22	July	0.27
Dandelion	7.59	June	0.17
Dry beans	17.46	July	0.29
Egg plant	19.18	August	0.26
Endive,Escarole, Lettuces (fall)	5.84	September	0.10
Endive,Escarole, Lettuces (spring)	7.42	May	0.16
Fennel	8.32	August	0.12
Grapes, Mature no cover 25% canopy	12.81	July	0.13
Grapes, Mature no cover 50% canopy	21.23	July	0.23
Grapes,1-2year; cover;10% canopy	8.12	July	0.08
Grapes,1-2year; no cover;10% canopy	6.34	July	0.06
Grapes,Mature; cover;25% canopy	16.41	July	0.18
Grapes,Mature; cover;50% canopy	24.68	July	0.28

Crop Name	Seasonal Consumptive use (inches)	Month	Peak ET
Grass Hay	30.35	July	0.29
Green Beans	14.00	June	0.28
Lima beans	19.17	August	0.26
Melons	21.34	July	0.32
Onion/Scallions (early)	6.59	May	0.12
Onions (late)	15.86	August	0.26
Pasture (grass)	31.22	July	0.29
Peaches	30.98	July	0.32
Pears	30.98	July	0.32
Peas (early)	8.37	May	0.15
Peas (late)	8.50	September	0.16
Peppers	16.77	July	0.25
Potatoes (fall)	22.61	August	0.30
Potatoes, (summer)	25.02	July	0.33
Pumpkins	16.71	August	0.24
Radish (early spring)	2.70	May	0.12
Radishes (late spring)	3.77	June	0.17
Radishes (late summer)	4.72	September	0.13
Rasberries	30.20	July	0.33
Sorghum (silage)	20.86	August	0.27
Soybeans	17.83	August	0.28
Spinach (early)	5.61	May	0.14
Spinach (late)	7.08	September	0.16
Spring Oats	16.67	June	0.27
Squash (summer)	16.23	July	0.27
Strawberries	9.04	June	0.18
Sugar beet	27.23	August	0.35
Sweet Corn (2nd planting)	14.08	June	0.22
Sweet Corn (3rd planting)	15.22	July	0.31
Sweet Corn (early)	13.09	June	0.26
Sweet Potatoes	22.44	August	0.30
Tomatoes	23.58	July	0.31
Watermelons	22.03	August	0.31
Winter wheat	16.14	June	0.24

Reference:
NRCS, Irrigation Water Requirements Software Program; NEH Chapter 2, Irrigation Water Requirements.

NEW JERSEY TABLE NJ 4.3
CROP GROWING SEASON AND CROP COEFFICIENT VALUES (Kc)

CROP NAME	GROWING SEASON		% GROWING SEASON Kc FACTORS									
	Begin Growth	End Growth	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
VEGETABLES												
Asparagus	1-Apr	10-Jun	0.25	0.43	0.69	0.95	1.00	1.00	1.00	1.00	0.93	0.25
Azalea	15-May	1-Oct	0.25	0.43	0.69	0.95	1.00	1.00	1.00	1.00	0.93	0.25
Beets	1-Apr	30-Jun	0.25	0.25	0.36	0.57	0.79	1.00	1.00	1.00	0.98	0.90
Broccoli	20-Jun	30-Sep	0.25	0.28	0.44	0.59	0.75	0.90	0.95	0.95	0.94	0.80
Bunch Onion	1-Apr	20-Jun	0.25	0.25	0.28	0.43	0.58	0.74	0.89	0.95	0.95	0.95
Cabbage	1-Apr	30-Aug	0.25	0.28	0.44	0.59	0.75	0.90	0.95	0.95	0.94	0.80
Carrots	1-May	15-Sep	0.25	0.25	0.50	0.75	1.00	1.00	1.00	1.00	0.88	0.70
Cauliflower	20-Jun	30-Sep	0.25	0.28	0.44	0.59	0.75	0.90	0.95	0.95	0.94	0.80
Celery	1-May	30-Oct	0.25	0.40	0.70	1.00	1.00	1.00	1.00	1.00	0.99	0.90
Collards	1-May	30-Aug	0.25	0.25	0.48	0.72	0.95	0.95	0.95	0.95	0.95	0.90
Cucumbers	30-Apr	5-Sep	0.25	0.27	0.51	0.74	0.90	0.90	0.90	0.90	0.83	0.70
Dandelion	1-Mar	15-Jun	0.25	0.25	0.33	0.51	0.70	0.89	0.95	0.95	0.95	0.90
Dry Onion	25-Mar	15-Sep	0.25	0.69	0.95	0.95	0.95	0.95	0.95	0.91	0.83	0.75
Egg Plant	15-May	30-Sep	0.25	0.25	0.43	0.64	0.86	0.95	0.95	0.95	0.89	0.80
Endive	15-May	15-Sep	0.25	0.25	0.33	0.51	0.70	0.89	0.95	0.95	0.95	0.90
Escarole	15-May	15-Sep	0.25	0.25	0.33	0.51	0.70	0.89	0.95	0.95	0.95	0.90
Fennel	15-May	15-Sep	0.25	0.25	0.33	0.51	0.70	0.89	0.95	0.95	0.95	0.90
Lettuce	1-May	5-Sep	0.25	0.25	0.33	0.51	0.70	0.89	0.95	0.95	0.95	0.90
Lima Beans	10-Apr	10-Jul	0.25	0.25	0.41	0.62	0.83	0.95	0.95	0.95	0.94	0.85
Muskmelons	1-May	30-Sep	0.25	0.25	0.53	0.82	1.10	1.10	1.10	1.10	0.95	0.65
Peas	10-Apr	10-Sep	0.25	0.25	0.55	0.84	1.05	1.05	1.05	1.05	1.02	0.95
Peppers	1-May	30-Aug	0.25	0.25	0.48	0.72	0.95	0.95	0.95	0.95	0.90	0.80
Potatoes	30-Mar	1-Oct	0.25	0.25	0.57	0.89	1.05	1.05	1.05	1.05	0.88	0.70
Pumpkins	20-Jun	20-Oct	0.25	0.25	0.47	0.68	0.90	0.90	0.90	0.90	0.80	0.70
Radish	1-Apr	15-May	0.25	0.25	0.43	0.62	0.80	0.80	0.80	0.80	0.79	0.75
Snap Beans	10-May	30-Sep	0.25	0.25	0.41	0.62	0.83	0.95	0.95	0.95	0.94	0.85
Spinach	30-Mar	30-May	0.25	0.25	0.48	0.72	0.95	0.95	0.95	0.95	0.95	0.90
Squash	15-May	1-Sep	0.25	0.25	0.47	0.68	0.90	0.90	0.90	0.90	0.80	0.70
Sweet Corn	1-May	30-Sep	0.25	0.25	0.43	0.66	0.89	1.03	1.03	1.03	1.02	0.95
Sweet Potatoes	15-May	1-Nov	0.25	0.25	0.57	0.89	1.05	1.05	1.05	1.05	0.88	0.70
Tomatoes	1-May	30-Sep	0.25	0.25	0.52	0.78	1.05	1.05	1.05	1.05	0.95	0.85
Watermelons	15-May	30-Sep	0.25	0.25	0.53	0.82	1.10	1.10	1.10	1.10	0.93	0.60
SMALL FRUIT/ORCHARDS												
Apples	10-Apr	30-Oct	0.50	0.75	1.00	1.00	1.00	1.10	1.10	1.10	0.85	0.85
Blueberries	15-Apr	15-Oct	0.46	1.10	1.10	1.10	1.04	0.97	0.87	0.82	0.75	0.67
Cranberries	1-Apr	1-Nov	0.40	0.40	1.05	1.10	1.10	1.10	0.85	0.50	0.40	0.40
Grapes	1-May	30-Oct	0.50	0.50	0.60	0.65	0.75	0.80	0.80	0.75	0.65	0.65
Peaches	1-Apr	30-Oct	0.50	0.70	0.70	0.90	1.00	1.00	1.00	0.95	0.75	0.75
Pears	1-Apr	30-Oct	0.50	0.70	0.70	0.90	1.00	1.00	1.00	0.95	0.75	0.75
Raspberries	15-Apr	15-Oct	0.40	1.05	1.05	1.05	1.05	1.05	.85	0.75	0.50	0.50
Strawberries	30-Aug	20-Feb	0.25	0.40	0.55	0.70	0.70	0.70	0.70	0.70	0.70	0.70
FIELD CROPS/ HAY LAND												
Alfalfa	30-Mar	15-Oct	0.25	0.44	0.72	0.99	1.05	1.05	1.05	1.05	0.98	0.25
Barley	1-Mar	1-Jul	0.25	0.53	0.93	1.05	1.05	1.05	1.05	0.89	0.57	0.25
Corn	10-May	15-Oct	0.25	0.35	0.69	1.03	1.20	1.20	1.20	1.15	0.87	0.60
Oats	1-Apr	31-Jul	0.25	0.53	0.93	1.05	1.05	1.05	1.05	0.89	0.57	0.25
Sorghum	30-May	10-Nov	0.25	0.37	0.65	0.94	1.00	1.00	1.00	0.90	0.70	0.50
Soybeans	30-May	10-Nov	0.25	0.42	0.76	1.00	1.00	1.00	1.00	1.00	0.74	0.45
Wheat	1-Mar	15-Jul	0.25	0.53	0.93	1.05	1.05	1.05	1.05	0.89	0.57	0.25

TABLE NJ 4.4
SUGGESTED BEFORE (Eb) AND AFTER (Ea) SYSTEM EFFICIENCIES

PROPOSED IRRIGATION METHOD	EFFICIENCY BEFORE	EFFICIENCY AFTER	IWM APPLIED
SPRINKLER IRRIGATION (TRAVELING GUN) Replace leaky alum. pipe with buried mainline.	45%	55%	65%
SPRINKLER IRRIGATION (HAND MOVE PORTABLE) Replace leaky alum. pipe with buried mainline	50%	60%	70%
SPRINKLER IRRIGATION (SOLID SET) Replace hand move to solid set ABOVE canopy.	50%	65%	75%
SPRINKLER IRRIGATION (SOLID SET) Replace hand move to solid set BELOW Canopy.	50%	70%	80%
SPRINKLER IRRIGATION (CENTER PIVOT/LINEAR MOVE) Replace leaky alum. Pipeline with buried main, impact nozzles on lateral.	60%	70%	80%
SPRINKLER IRRIGATION (CENTER PIVOT/LINEAR MOVE) Renozzle to LEN and LDN nozzles on drops in canopy, replace leaky alum. Pipe with buried mainline	60%	85%	88%
SPRINKLER IRRIGATION (CENTER PIVOT/LINEAR MOVE) Replace traveling gun to center pivot, and renozzle to LEN and LDN nozzles on drops in canopy.	55%	85%	88%
DRIP/MICRO IRRIGATION Replace traveling gun with drip and replace leaky alum. Pipe with buried main.	45%	85%	90%
DRIP/MICRO IRRIGATION Replace traveling gun with drip, existing buried main.	55%	85%	90%
DRIP/MICRO IRRIGATION Replace hand move to drip and replace leaky alum. Pipe to buried mainline.	50%	85%	90%
DRIP/MICRO IRRIGATION Replace hand move with drip, existing buried mainline.	60%	85%	90%
DRIP/MICRO IRRIGATION Replace solid set to drip/micro.	70%	85%	90%
SUBSURFACE DRIP (SDI) Replace surface drip with buried drip laterals >6" depths.	85%	90%	95%

Reference: Soil Conservation Service, Farm Irrigation Rating Index (FIRI)

(c) Management Allowed Soil-Water Depletion

Management Allowed Depletion (MAD) is generally defined for each local crop. It is a grower's management decision based on yield and product quality objectives whether or not to fine tune generalized MAD values. MAD is the greatest amount of water to be removed by plants before irrigation so that undesirable crop water stress does not occur. The determination of when and how much to apply requires a knowledge of the available water holding capacity (AWC) of the soil, the plant stress level for the specified crop, the peak consumptive use, crop rooting depth, and the critical periods in the growing season when a crop should not be stressed, or may need to be stressed for higher quality fruit (wine grapes). Historically, an allowable depletion of between 30 and 60 percent of the soil Available Water Capacity (AWC) has been used for management purposes. See Chapter 3, Crops, for summary of recommended MAD levels for various crops. Most crops should be irrigated before more than half of the available moisture in the crop root zone has been used. Some crops, however, are thought to do better at higher moisture levels (less moisture deficiency at time of irrigation), while some require higher depletion levels at different growth stages (deficit irrigation in wine grapes). Refer to Chapter 3, Crops, National Irrigation Guide and NJIG, for a summary of recommended MAD levels for various crops. Irrigation must begin so that the entire area to be covered can be irrigated before the available moisture level in the last portion of the field reaches a point to cause unfavorable moisture stress to the crop. This aspect of management is crucial for systems that may need several days to irrigate the entire field area, such as traveling guns and hand move laterals.

Estimated irrigation frequency, in days, is based on the MAD level for the AWC in the total crop root zone and the estimated crop ET.

Irrigation frequency in days can be determined by:

$$\frac{\text{MAD x AWC for crop root zone in inches}}{\text{Daily ETc rate in inches/day}}$$

(d) Auxiliary Water Requirements

In addition to crop evapotranspiration water requirements, irrigation systems can also meet special needs of crops and soils. In New Jersey, sprinkler irrigation is extensively used for frost protection on cranberries, blueberries, orchard and strawberries. Sprinkler systems are also used for crop cooling. Chemicals (fertilizers, pesticides, etc.) are also 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.

Frost Control

For frost control, the irrigation system must have enough capacity to cover the entire area with a fine mist of water, (application rates 0.1"/hr or less). Irrigation for frost control 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 degrees F. The ice acts as a buffer against cooling of plant surfaces by radiation or contact with cold air. The principle is valid and 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. Each gallon of water at 32 degrees F., changing into ice at 32 degrees F gives off 1,200 BTU's of heat. Properly designed and operated systems can provide protection for certain crops to temperatures as low as 15 degrees F. Reports indicate that celery has been protected to 15F, cranberries to 16F, strawberries to 16F, tomatoes to 26F, blueberries to 24F, peppers to 21F, gladioli to 27F, hydrangea to 20F, and cherries to 23F. The rate of water application for frost protection depends somewhat on the air temperature. As the air temperature lowers, more water must be applied to provide protection. The degree of crop frost protection available and the optimum sprinkling procedures to be used are a function of the crop's resistance to freezing, stage of growth, general weather conditions, and the design and operation of the system. Table NJ 4.5 gives recommended application rates for strawberries. An application rate of 0.10 inch per hour is recommended for frost protection of cranberries in the critical spring and fall periods.

TABLE NJ 4.5 RECOMMENDED APPLICATION RATES FOR STRAWBERRIES

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

TABLE NJ 4.6 GALLONS PER MINUTE NEEDED FOR VARIOU5 APPLICATION RATES FOR EACH ACRE TO BE FROST PROTECTED

Application Rate (inches/hour)	0.08	0.09	0.10	0.11	0.125	0.15	0.20
Gallons per Minute per Acre	39	43	48	53	60	73	97

System Operation - The frost control system should be turned on when air temperature at the plant level reaches 34 degrees F. An alarm system consisting of a thermo-switch set in the field at the plant level and wired to an alarm bell in the house will alarm the operator when to turn the 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 constant 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, and plants which are not broken by the weight of ice. The weight of the accumulated ice may often damage tall-growing vegetable plants and fruit trees.

Sprinklers - Single-nozzle low-gallonage 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 specified pressure range for the particular sprinkler should be used to obtain both good coverage and finer water droplets desirable for frost protection. Sprinklers spaced in a triangular pattern, rather than a square or rectangular one, provide more uniform coverage. Sprinkler performance charts should be used as a guide for selecting sprinklers. Clean water is also a must, since foreign material in the water can easily clog the small sprinkler orifices.

<u>Crop Cooling</u>

Practical experience and research have proven that increased yields can be expected if crops are cooled by moisture supplied with sprinkler systems when temperatures above 90^0F prevail for extended periods of time. Cooling a crop is accomplished by drifting moist air over the field, which will cause a drop in the temperature and reduce the transpiration rate of the plants. A sufficient number of sprinklers must be operated simultaneously, and water pressure in the system must be sufficient to provide good breakup at the nozzle, if an effective moisture pattern is to be achieved. Plants cannot draw sufficient moisture through their structures to meet transpiration requirements if temperatures are much higher than 90^0F. for a few hours per day for several successive days. This is true even if there is sufficient moisture in the root zone to support normal plant development and growth. If extremely high temperatures continue, a plant will begin to draw moisture from its own produce --blossoms, stems, or fruit -- causing cell breakdown and subsequent fruit dropping.

Sprinkler cooling should be started when the temperature reaches 90^0F and water application continued until it drops back to that level. Several research and testing projects have indicated that the extra water used for crop cooling is offset by a savings in water normally drawn from the soil reservoir during the same period. Even if extra water is used, the results are reflected in higher quality yields. For crop cooling, the entire field must either be covered continuously or by a frequent cycling operation. This practice will reduce field temperatures around the plant as much as 15 degrees during periods of high temperatures.

<u>Fertilizer and Chemical Application</u>

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 can be applied with irrigation water, regardless of the methods used for water distribution. Equipment designed to inject fertilizer solutions into the water system is considered an integral part of practically all microirrigation designs offered on today's market. Likewise, injector pumps and metering devices are frequently considered as a standard component of any newly installed microirrigation and sprinkler system. 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 possibility shores up the arguments for the concept of "spoon feeding" a growing crop by applying smaller amounts of fertilizer at regular irrigation intervals throughout the season than with 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 when 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 significant 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 and are recommended for sprinkler, gated pipe, and other type systems using aluminum pipe, as well as for open ditch distribution.

Anhydrous ammonia can cause encrustation problems with some irrigation waters, if they are distributed through gated pipe. The irrigator should know the mineral content of the water supply and should be further aware of the fact that water sources can vary in mineral content from season to season and even change during an irrigation season.

If anhydrous ammonia is used with sprinkler systems, a high loss of ammonia can be expected when it is sprayed into the air and salts can plug the sprinkler nozzles if the water is not compatible with this type of fertilizer. To sum up the limitations, anhydrous and aqua ammonia can be used through siphon tubes in most waters and with gated pipe systems in some waters, but neither should 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 water supply.

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 certainly become 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 in combination with sprinkler irrigation 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 at the same time cutting labor costs and reducing trips over the field with equipment during the growing season.

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.

Although many successful metering devices have been designed that can be made from sprayer parts and other "around the farm" materials, the refined accuracy of the commercial fertilizer pumps makes them the most desirable devices to use.

Most fertilizer dealers can furnish data charts to help the irrigator determine how many gallons per hour of solution should be added to the water supply, and their advice can be confidently followed in most cases.

Recent trials and tests indicate that a uniform mix can be expected if the solution is added at any point near the initial water source. Some authorities advise the installation of the line on the suction side of a centrifugal pump, but satisfactory mixtures have been obtained by injecting the fertilizer on the pressure side of such pumps. Most metering pumps are high pressure, positive displacement types, and deliver the fertilizer into the pipeline at pressures higher than the water therein. Fertilizer should be injected into sprinkler systems at some point near the pump.

Injector Pumps - Any irrigator using an electric-powered metering-injecting pump for fertilizer 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 polluted 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 fertilizer and pesticides into the water supply with the same unit. These models can be used to handle large amounts of fertilizer if the desired application exceeds the capacity of the single pump.

Phosphates - Numerous trials and tests have been conducted by irrigators desiring to add phosphorus to the soil by applying ammonium polyphosphate, through irrigation water. Both surface methods and sprinkler systems have been used in these experiments. Present indications are that the phosphate can be moved to the proper root zone depth in sandy soils, but penetration of soils with clay content has proved very shallow.

(e) Water Requirements for Soil-Water Budget/Balance Analysis

The components of a soil-water budget/balance analysis must include all water going *in* and water going *out* of an area for the period of consideration. The basic purpose of such an analysis is to determine the location of all water applied.

An example of a simplified soil-water budget in New Jersey is as follows:

Crop = tomatoes
Mature rooting depth = 24”
Total AWC = 3.1”
MAD = 25%
Field Capacity at start of season
Drip Irrigation with gross application = 0.8”
Application efficiency = 90%
Net application/irrigation = 0.7”
DU = 100% no surface runoff
No contribution from a shallow water table
Effective Precipitation (Reference Irrigation Water Requirements, Technical Release 21).

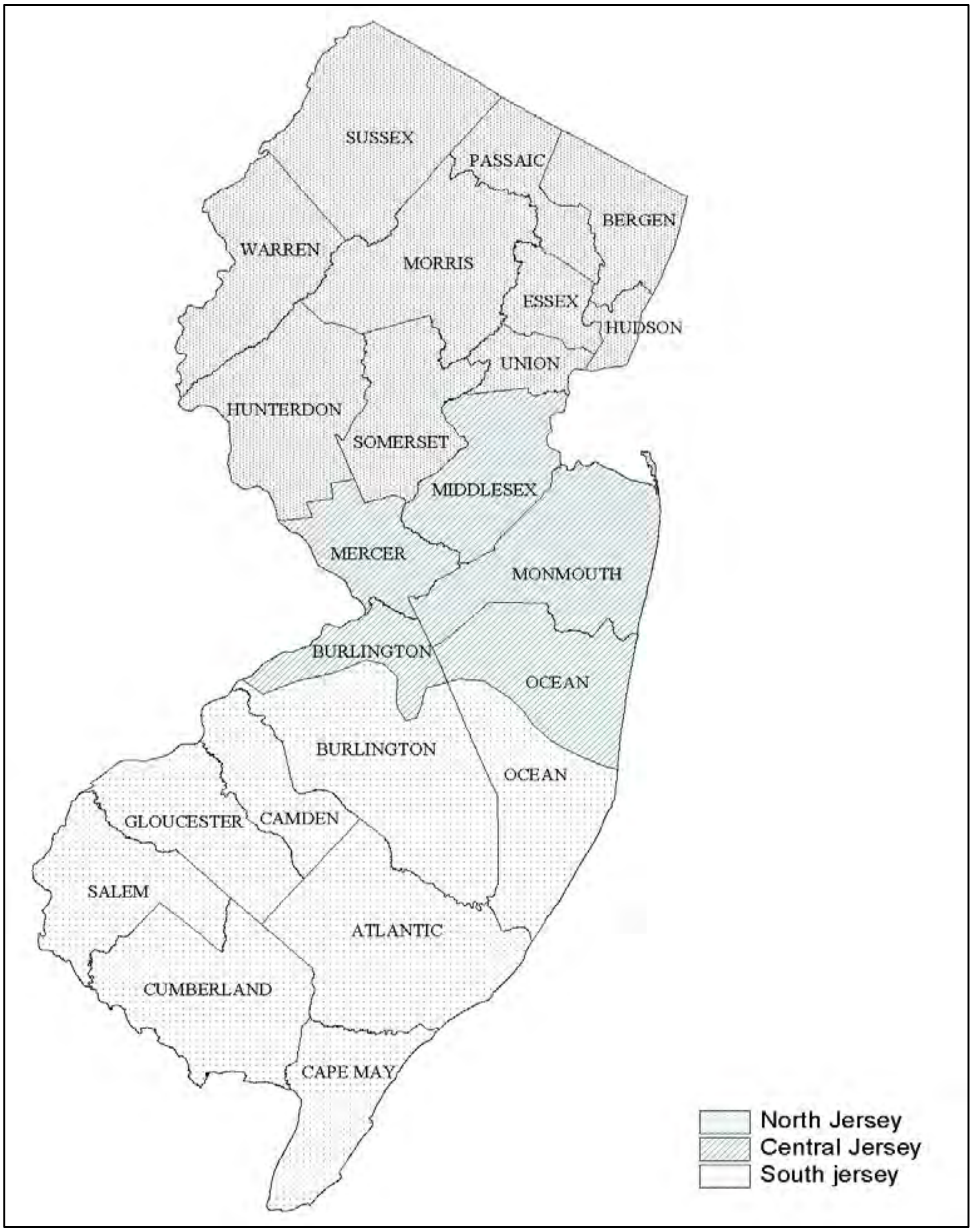
All crop ET, irrigation, and precipitation units are in inches. Additional and more detailed examples of a soil-water budget/balance are in Chapter 8, Project and Farm Irrigation Water Requirements, National Irrigation Guide.

Table NJ 4.7 Example Soil-Water Budget

Month	Crop ET	Soil Water Used	Precipitation		Irrigations		Water	
			Total	Effect 1/	No.	Net Water Applied	Deficit	Surplus
May	.87	.87	3.51	.87	0	0	0	0
June	3.36	3.36	3.58	1.49	3	2.1	0	.23
July	7.57	7.57	4.31	2.22	7	4.9	.45	0
Aug	7.25	7.7	4.06	2.07	8	5.2	.43	0
Sept	4.35	4.78	3.55	1.53	4	2.8	.45	0
Total	23.4	24.3		8.18	22	15		.23 2/

1/ Assuming all effective precipitation infiltrated into the soil.
2/ Typically lost to deep percolation. The total is in inches.

Figure NJ 4.1
IRRIGATION ZONES OF NEW JERSEY



(f) Water Sources

The sources of irrigation water most common in New Jersey are wells, irrigation pits with ground water recharge, flowing streams, surface reservoirs, 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 probable amount or quantity of water that can be obtained from a well that is drilled at any given location. Information, however, is available in New Jersey through records maintained by the Department of Environmental Protection, Bureau of Water Allocation. These records can assist by providing information regarding depth and yield of other wells drilled in the vicinity. A permit is required to drill a well and all wells must be drilled by a New Jersey licensed well driller.

Irrigation Pits with Ground Water Recharge

Ground water pumped from shallow pits is a common source of supply in New Jersey. The ground water level determines the maximum water level in the pit and should be close enough to the surface to be available when needed. Highly permeable gravel or sand provides better recharge than soils with silts or clays. Munch and Spence in the Freehold District 1956 Annual Report gave rule-of-thumb recharge estimates based on field testing of 20 pits as shown in Table NJ 4.8. These rates are per 1000 cubic yards of excavation below the water table with an average depth below the water table of 9 feet and average pond width of 60 feet. A few deep auger holes at the dry time of year can be used to determine the material, depth to ground water, and direction of ground water flow. Most irrigation pits are not large enough to store all of the water needed for an irrigation season so recharge is necessary. The depth, shape, and orientation of the pit affect the recharge rate. The rate of ground water flow into the pit is approximately proportional to the reduction of the water level in the pit. For example, when the pit and ground water levels are equal, no recharge occurs. When the pit water level is 6 feet below the ground water level, the recharge rate will be approximately 3 times as high as when the pit water level is 2 feet below the ground water level. As a guide, the minimum storage volume of a pit with good recharge should be large enough to supply water for one complete irrigation of the entire irrigated area, or about 1 to 1 ½ acre-inches for each irrigated acre. The storage volume must be larger if the anticipated recharge rate will not replenish the storage during the irrigation interval.

Table NJ 4.8 Estimated Recharge Rates

Soil Material	Intake Rate per 1000 cy Gallons per minute
Sharpe, coarse sand and medium gravel i.e. Pensauken	12
Medium to coarse sand i.e. Red Bank	6
Fine to medium fine sand with clay and silt	3
Tight clay	No measurable intake

The maximum suction lift for irrigation pumps is about 22 feet. This is the distance from the water surface to the center of the pump. Pits should be as deep as possible for good recharge but should not exceed 22 feet.

The long side of a pit should be at a right angle to the direction of ground water flow to obtain maximum recharge. The direction of flow can be determined with three observation wells (auger holes) drilled about 300 feet apart on the vertices of a triangle. Take the elevations of the ground water surface at each well and plot the ground water contour lines. The direction of flow is at a right angle to the contour lines.

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 withdrawals from stream sources.

Reservoirs

A reservoir, either excavated or embankment, 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 reservoir 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 reservoir between irrigations.

Public Water Supplies

Public supplies are more likely to be used when the volume of water required is small and the pressure requirements are compatible with the local system. Therefore, a small mircoirrigation system 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.

NJ652.05 Irrigation Method Selection

(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 New Jersey along with their adaptability and limitations. Also refer to National Engineering Handbook (NEH), Part 623, Section 15, chapters 3-9, and 11, and National Irrigation Guide, Chapter 5.

(b) Methods and Systems to Apply Irrigation Water

The four basic irrigation methods, along with the many systems to apply irrigation water, include: sprinkler, surface, micro, and subirrigation.

Sprinkler -A majority of the irrigation in New Jersey consists of the sprinkler type. This method applies water through a system of nozzles (impact and 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 of less than 0.1 inch per hour to more than 2 inches per hour. Sprinkler irrigation systems include the following: Solid Set, Handmove Laterals, Sideroll (wheel) Laterals, Center Pivot, Linear Move, and Traveling and Stationary Guns. Low Energy Precision Application (LEPA) and Low Pressure in Canopy (LPIC) systems are included with sprinkler systems because they use center pivot and linear move irrigation systems.

Surface – This irrigation method involves the distribution of water by gravity over the soil surface either in a sheet or in furrows. Land leveling is generally required to obtain the proper soil slope for uniform water distribution.

Surface irrigation is practiced extensively in New Jersey cranberry bog management, primarily for frost control, harvesting and winter flooding. Surface irrigation has been supplemented with solid set sprinkler systems. These systems provide irrigation water for peak crop consumptive use as well as cooling and frost control. Sprinkler systems use much less water and can start operation within a few minutes, whereas it takes several hours to flood a bog for frost protection. Flooding is still used for winter-flooding to protect vines from freezing temperatures and for water-harvesting operations.

Micro – Water is applied through low-pressure, low volume discharge devices (drip emitters, line source emitters, micro spray and sprinkler 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 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 root zone. Micro irrigation is adaptable to many specialty fruits and vegetables grown in New Jersey and is increasing in acreage each year, replacing many lower efficiency sprinkler systems such as the hand move laterals and traveling gun systems. This is resulting in a water and energy savings along with improved yield quality and quantity.

Subirrigation - Water is made available to the crop root system by upward capillary flow through the soil profile from a controlled water table. In New Jersey this is done through a system of ditches or tile drains. To be successful, the topography must be nearly level and smooth. The upper soil layers must be permeable to permit free and rapid water movement laterally and vertically. The permeable soil must be underlain by relatively impervious soil on which an artificial water table can be built up or it must have a natural high water table. Controlled drainage of muck soils has been the most common use of subsurface irrigation. Blueberries and cranberries, traditionally grown on wetland soils, are supplemented with this method of irrigation. A series of ditches and water control structures are used to maintain the water table level. If necessary, well water is also pumped into the ditches to fill and maintain the water table

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Tables

during the growing season. This method is also supplemented with sprinkle and micro irrigation.

Each irrigation method and system has 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
- costs

c) Site Conditions

Refer to Table 5-1 in the National Irrigation Guide, page 5-3, Site Conditions to Consider in Selecting an Irrigation Method and System.

d) Selection of Irrigation Method and System

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

Table NJ 5.1, displays estimated typical life and annual maintenance for irrigation system components.

e) Adaptability and Limitations of Irrigation Methods and Systems

Sprinkler Systems

Solid Set, Permanent

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

Solid Set, Portable

- Low labor requirement because the pipe does not have to be moved while in the field.
- Adaptable to irregular fields and rolling terrain
- Allows for light applications at frequent intervals
- Adaptable for high value crops such as vegetables, and nursery stock.
- Can be used to germinate crops that will later be drip irrigated.
- Entire system can be operated at one time for frost control and crop cooling at low application rates < 0.15”/hr.
- High initial cost of needing sufficient lateral pipe and sprinklers to cover the entire field.
- Wind drift and evaporation problems with low application rates < 0.15”/hr.
- Not easily automated.
- Efficiency is lower then permanently installed solid set due to leaky pipe connections and runoff.
- Caution must be taken during tillage and harvest operations to prevent damage to pipeline, risers and sprinkler heads.

Hand Move Lateral

- 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

Side or Wheel Roll

- Adaptable to irrigating potatoes, vegetables, field crops, and alfalfa hay
- Low labor requirement
- Higher initial costs and maintenance costs then hand move laterals

- Field must be rectangular
- Not adapted to tall crops
- Topography must be flat or gently rolling

Center Pivot
- 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 at the outer end may cause runoff and erosion problems.
- Drive wheels may cause ruts in some soils.
- Requires uniform topography with slopes <10%

Linear Move
- Adaptable for irrigating corn, potatoes, vegetables, field crops, and alfalfa hay.
- Easily automated
- Can irrigate an entire field
- Uniform water application
- Requires rectangular fields
- Higher labor then a center pivot but less then a hand move system.
- Requires uniform topography with slopes <10%.

Traveling Gun
- 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 crop.
- Wind seriously affects the distribution pattern, causing non-cropped areas to be wetted.
- Low efficiency due to high evaporation and runoff potential.

Microirrigation
- Highest potential application efficiency-low runoff and evaporation losses.
- Highest design distribution uniformity.
- Spoon feeding directly to root zone.
- High yields and excellent quality.
- Low water use enables small water supplies to be utilized.
- Requires 50% of the water needed for an overhead system.
- Low pumping costs due to low pressure and flow requirements
- Pipe network can be smaller then high pressure/flow systems and therefore less costly.
- Disease control is high since leaves are not wetted.
- Ability to fertigate through system resulting in less fertilizer applied.
- Extensive automation is possible.
- Field operations can continue while irrigating.
- Adaptable to irregular shaped fields.
- Entire system can be operated at one time.
- High degree of filtration and pressure regulation required.
- High maintenance required and management skills.
- 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 some other methods.

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

<u>Line Source Tape</u>

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

<u>Micro Spray/Sprinkler</u>

- Adaptable for irrigating orchards, nursery trees and container stock.
- Provides frost control in orchards with new applications in vineyard and small fruit.
- Application uniformity can be affected by wind.
- Higher evaporation losses.

Subsurface Irrigation

<u>Open Ditches with Control Structures</u>

- In NJ mostly adapted to blueberry and cranberry production.
- Topography must be level or slopes very gentle and uniform.
- Adaptable to soils with low available water holding capacity and high intake rates.
- Soil must have either a natural high water table or impermeable layer in the substratum.

Tables NJ 5.2 – NJ 5.5 display factors that affect the adaptation and operation of various irrigation methods and systems. In these tables, + indicates positive effects or preferred selection, the – indicates negative effects or provides possible reasons for not choosing this alternative (another system or method should be considered, and 0 indicates neutral effect or should provide no influence on selection.

Table NJ 5.6 gives recommended slope limitations for sprinkler systems.

Table NJ 5.1 Typical life and annual maintenance cost percentage for irrigation systems components

System and components	Life (yr)	Annual maint. (% of cost)	System and components	Life (yr)	Annual maint. (% of cost)
Sprinkler systems	10 - 15	2 - 6	**Surface & subsurface systems**	15	5
Handmove	15 +	2			
Side or wheel roll	15 +	2	Related components		
End tow	10 +	3	Pipelines		
Side move w/drag lines	15 +	4	Burled thermoplastic	25 +	1
Stationary gun type	15 +	2	Buried steel	25	1
Center pivot-standard	15 +	5	Surface aluminum	20 +	2
Linear move	15 +	6	Surface thermoplastic	5 +	4
Cable tow	10 +	6	Hurled nonreinforced concrete	25 +	1
Hose pull	15 +	6	Buried galv. steel	25 +	1
Traveling gun type	10 +	6	Buried corrugated metal	25 +	1
Fixed or solid set			Buried reinforced PMP	25 +	1
Permanent	20 +	1	Gated pipe, rigid, surface	10 +	2
Portable	15 +	2	Surge valves	10 +	6
Sprinkler gear driven, impact & spray heads	5 - 10	6			
			Pumps		
Valves	10 - 25	3	pump only	15 +	3
			w/electric motors	10 +	3
Micro systems [1/]	1 - 20	2 - 10	w/internal combustion engine	10 +	6
Drip	5 - 10	3			
Spray	5 - 10	3	Wells	25 +	1
Bubbler	15 +	2	Linings		
Send-rigid, hurled	10 - 20	2	Nonreinforced concrete	15 +	5
Semi-rigid, surface	10	2	Flexible membrane	10	5
Flexible, thin wall, buried	10	2	Reinforced concrete	20 +	1
Flexible, thin wall, surface	1 - 5	10			
Emitters & heads	5 - 10	6	Land grading, leveling[2/]		
Filters, injectors, valves	10 +	7	Reservoirs[3/]		

1/ With no disturbance from tillage and harvest equipment.
2/ Indefinite with adequate maintenance.
3/ Indefinite with adequate maintenance of structures, watershed.

Table NJ 5.2 Factors affecting the selection of periodic move, fixed, or solid set sprinkler irrigation systems

Item	----Periodic move----			----Solid set or fixed----		
	sideroll	hand	gun	perm	port	gun
Crop						
Field—close growing	0	0	0	0	0	0
Field—row	0	0	0	-	0	-
Vegetable—fresh	0	0	0	0	0	0
Vegetable—seed	-	-	-	-	-	-
Orchards, berries, grapes	-	0	-	+	+	-
Alfalfa hay	0	0	0	-	-	-
Corn	-	-	0	-	-	0
Cotton	-	-	-	-	-	-
Potatoes, sugar beets	0	0	0	-	0	-
Land & soil						
Low AWC	0	0	0	+	+	+
Low infiltration rate	0	0	-	0	0	-
Mod- infiltration rate	0	0	0	0	0	0
High infiltration rate	0	0	0	+	+	+
Variable infiltration rate	+	+	+	+	+	+
High salinity or sodicity	-	-	-	-	-	-
Highly credible	+	+	-	+	+	-
Steep & undulating Togo	-	+	-	0	0	-
Odd shaped fields	-	0	+	+	+	+
Obstructions 1/	-	0	0	-	0	0
Stony, cobbly	0	0	0	0	0	0
Water supply						
Low cont. flow	+	+	+	+	+	+
High intermit, flow	-	-	-	-	-	-
High salinity or sodicity	-	-	-	-	-	-
High sed. content	-	-	-	-	-	-
Delivery schedule						
continuous	+	+	+	+	+	+
rotation	-	-	-	-	-	-
arranged, flexible	0	0	0	0	0	0
demand	0	0	0	0	0	0
Climate						
High rainfall	+	+	+	+	+	+
Low rainfall—arid	0	0	0	0	0	0
Windy	-	-	-	-	-	-
High temp—humid	+	+	+	+	+	+
High temp—arid	-	-	-	-	-	-
Social/institutional						
Automation potential	-	-	-	+	+	0
Easy to manage	0	0	0	+	+	+

1/ Obstructions may include roads, buildings, rock piles, trees, above and below ground utilities, and oil pipelines.

Table NJ 5.3 Factors affecting the selection of continuous/self moving[1/] sprinkler irrigation systems

Item	----LEPA[2/]----		----LPIC[3/]----		--Center pivot--		----Linear----		
	Center pivot	linear	Center pivot	linear	high press	low press	high press	low press	gun
Crop									
Field-close growing	-	-	-	-	0	0	0	0	0
Field-row	0	0	0	0	0	0	0	0	0
Vegetable-fresh	0	0	0	0	0	0	0	0	0
Vegetable-seed	0	0	0	0		-		-	-
Orchard, berries, grapes	-	-	-	-	-	-	-	-	-
Alfalfa hay	-	-	-	-	0	+	0	+	0
Corn	0	0	0	0	0	0	0	0	0
Cotton	0	0	0	0	-	-	-	-	-
Potatoes, sugar beets	0	0	0	0	0	0	0	0	0
Land & soil									
L0wAWC	+	+	+	+	+	+	+	+	0
Low infiltration rate	0	0	-	-	-	-	-	-	-
Mod. infiltration rate	0	0	0	0	-	-	0	0	0
High infiltration rate	+	+	+	+	+	+	+	+	+
Variable infiltration rate	+	+	+	+	+	+	+	+	+
High salinity and sodicity	0	0	0	0	0	0	0	0	0
High erodible	0	0	0	0	-	-	-	-	-
Steep & undulating topog	-	-	-	-	-	-	-	-	+
Odd shaped fields	-	-	-	-	-	-	-	-	+
Obstructions[4/]	-	-	-	-	-	-	-	-	+
Stony, cobbly	0	0	0	0	0	0	0	0	0
Water supply									
Low cont. flow rate	+	+	+	+	+	+	+	+	+
High intermit. flow rate	-	-	-	-	-	-	-	-	-
High salinity	-	-	-	-	-	-	-	-	-
High sed. content	-	-	-	-	-	-	-	-	-
Delivery schedule									
continuous	+	+	+	+	+	+	+	+	+
rotation	-	-	-	-	-	-	-	-	-
Arranged, flexible	0	0	0	0	0	0	0	0	0
demand	0	0	0	0	0	0	0	0	0
Climate									
Humid & subhumid	+	+	+	+	+	+	+	+	+
Arid & semiarid	0	0	0	0	0	0	0	0	0
Windy	+	+	+	+	-	-	0	0	-
High temp-humid	+	+	+	+	+	+	+	+	+
High temp-arid	0	0	0	0	0	0	0	0	0
Social/institutional									
Automation potential	+	-	+	-	+	0	-	-	-
Easy to manage	0	0	0	0	0	0	0	0	0

1/ Continuous/self moving describes a sprinkler system that is self moving in continuous or star-stop operations.
2/ LEPA-Low Energy Precision Application system (in-canopy with good soil and water management).
3/ LPIC-Low Pressure In Canopy system.
4/ Obstructions may include roads, buildings, rock piles, trees, and aboveground utilities.

Table NJ 5.4 Factors affecting the selection of micro irrigation systems [1/]

Item	Point source drip emitter	Line source cont. tube	Micro spray/ sprinkler	Basin bubbler
Crop				
Field—close growing	-	-	-	-
Field row	-	0	-	-
Vegetable fresh	-	+	-	-
Vegetable seed	-	0	-	-
Orchards, berries, grapes	+	-	+	+
Alfalfa hay	-	-	-	-
Corn	-	0	-	-
Cotton	-	+	-	-
Potatoes, sugar beets	-	0	-	-
Land & soil				
LowAWC	+	+	+	+
Low infiltration rate	0	0	0	0
Mod. infiltration rate	0	0	0	0
High infiltration rate	+	+	+	0
Variable infiltration rate	+	+	+	+
High salinity and sodicity	0	+	+	0
Highly erodible	+	+	+	0
Steep & undulating topog	+	-	+	-
Odd shaped fields	+	+	+	+
Obstructions[2/]	+	+	+	+
Stony, cobbly	+	+	+	+
Water supply				
Low cont. flow rate	+	+	+	+
High intermit. flow rate	-	-	-	-
High salinity	-	-	-	-
High sed. content	-	-	-	-
Delivery schedule				
continuous	+	+	+	+
rotation	-	-	-	-
arranged, flexible	0	0	0	0
demand	0	0	0	0
Climate				
Humid & subhurnid	0	0	0	0
Arid & semiarid	0	0	0	0
Windy	+	+	-	0
High temp—humid	0	0	0	0
High temp arid	0	0	0	0
Social/institutional				
Easy to manage	-	-	-	-
Automation potential	+	+	+	+

1/ Not suitable unless water supply is non-saline, low SAR, and very high quality.
2/ Obstructions may include roads, buildings, rock piles, trees, and below-ground utilities.

Table NJ 5.5 Factors affecting the selection of subirrigation systems[1/]

Item	Water table control	Item	Water table control
Crop		**Water supply**	
Field - close growing	0	Low cont. flow rate	+
Field - row	0	High intermit flow rate	-
Vegetable - fresh	0	High salinity	-
Vegetable - seed	0	High sed. content	-
Orchards, berries, grapes	0		
Alfalfa hay	-	**Delivery schedule**	
Corn	0	continuous	+
Cotton	-	rotation	-
Potatoes, sugar beets	0	arranged, flexible	-
		demand	0
Land & soil			
Low AWC	0	**Climate**	
Low permeability	0	High rainfall	+
Mod. permeability	+	Low rainfall - arid	-
High permeability	0	Windy	+
Variable infiltration rate	0	High temp - humid	+
High salinity and sodicity	-	High temp - arid	+
Highly erodible	0		
Undulating topography	-	**Social & institutional**	
Odd shaped fields	0	Easy to manage	0
Obstructions [2/]	0	Automation potential	0
Stony, cobbly	-		

1/ Not suitable unless water supply is nonsaline, low salt, and very high quality.
2/ Obstructions may include roads, buildings, rock piles, trees, and belowground utilities.

Table NJ 5.6 Slope limitations for sprinkler irrigation systems

Type	Maximum slope (%)[1/]	Comments
Periodic move/set		Laterals should be laid cross slope to minimize and control pressure variation. Consider using pressure or flow control regulators in the mainline, lateral, or individual sprinkler spray heads, when pressure differential causes an increase of > 20 % of design operating pressure.
portable handmove	20+/-	
sideroll - wheel mounted	10	
gun type	20+/-	
end tow	5-10	
Fixed (solid) set		
permanent laterals	no limit	
portable laterals	no limit	
gun type	no-limit	
Continuous move		
center pivot	15	
linear move	15	
gun type	20+/-	
LEPA		
center pivot	1.0	
linear	1.0	
LPIC		
center pivot	2.5	
linear	2.5	

1/ Regardless of type of sprinkler irrigation system used, runoff and resulting soil erosion becomes more hazardous on steeper slopes. Proper conservation measures should be used; i.e., conservation tillage, crop residue use, filter strips, pitting, damming-diking, terraces, or permanent vegetation.

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NJ652.06 Irrigation System Design

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 a conservation irrigation system matches soil and water characteristics with water application rates 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 lines and spacing the sprinklers or emitters, and in selecting the type of mechanized system. The location of the water supply, capacity, and the source of water will affect the size of the pipelines, irrigation system flow rates, and the size and type of pumping plant to be used. The power unit selected will be determined by the overall pumping requirements and the energy source available.

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 crop-water requirement.
- Application rates must not exceed the maximum allowable infiltration rate for the soil type. Excess application rates will result in water loss, soil erosion, and possible surface sealing. As a result, there may be inadequate moisture in the root zone after irrigation, and the crop could be damaged.
- Flow rates must be known for proper design and management.
- Soil textures, available soil water holding capacity, and crop rooting depth must be known for planning and designing system application rates, irrigation water management, and scheduling irrigations so that water applied is beneficially used by the crop.
- The water supply, capacity, and quality need to be determined and recorded.
- Climatic data - precipitation, wind velocity, temperature, and humidity must be addressed.
- Topography and field layout must be recorded.
- Farmer’s preferences in irrigation methods, available operation time, farm labor, cultural practices, and management skills must be noted for selecting and planning the type and method of irrigation.

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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 Engineers, and the National Irrigation Association.

Material and equipment used should conform to the standards of the American Society for Testing Materials (ASTM) and the Irrigation Association.

b) Sprinkler Irrigation Systems

The three main types of sprinkler systems are classified as fixed, periodic move, and continuous/self move systems.

Fixed Systems include solid set (portable or permanent pipeline). There are enough laterals and sprinklers that none have to be moved to complete an irrigation. In New Jersey this method is used predominantly on blueberries and cranberries for both irrigation and frost control.

Periodic Move Systems include handmove laterals, side roll laterals, end tow laterals, hose fed (pull) laterals, gun type sprinklers, boom sprinklers, and perforated pipe. In New Jersey the hand move, stationary gun, and some side roll/wheel roll systems are used primarily on vegetable crops.

Continuous Move/Self Move Systems include center pivots, linear move laterals, and traveling gun sprinklers.

Pressure for sprinkler systems is generally provided by pumping powered mainly by diesel or electric and some gasoline engines. If the system is properly designed and operated, application efficiencies of 50% - 95% can be obtained. This depends on the type of system, cultural practices, and management. Poor management (i.e. irrigating too soon or applying too much water) is the greatest cause of reduced water application efficiency. Refer to Table NJ 6.1 for efficiency values of various types of sprinkle systems.

System losses are caused by the following:

- Direct evaporation in the air from the spray, from the soil surface, and from plant leaves that intercept spray water.
- Wind drift (normally 5% – 10% losses, depending on temperature, wind speed, droplet size).
- Leaks and system drainage
- Surface runoff and deep percolation resulting from nonuniform application within the sprinkler pattern.

If the system is designed to apply water at less than the maximum soil infiltration rate, no runoff losses will occur. With some systems where water is applied below or within the crop canopy, wind drift and most evaporation losses are reduced.

Table NJ 6.1 Application efficiencies for various sprinkler systems

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

On sloping sites where soils have a low to medium intake rate, runoff often occurs under center pivot systems, especially at the outer end of the sprinkler lateral.

Planning and design considerations and guidelines should be referenced to NEH, Part 623, (Section 15), Chapter 11, Sprinkle Irrigation. Operating pressures for these guidelines are grouped as follows:

- Low Pressure 2 – 35 psi
- Moderate Pressure 35 – 50 psi
- Medium Pressure 50 – 75 psi
- High Pressure 75+

1) Fixed –Solid Set Sprinkler Systems

Solid set sprinkler systems consist of either an above ground portable pipe system (aluminum pipe) or a permanently buried 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 crop season. A portable solid set system can be moved to a different field at the end of a particular crop season. A permanent solid set system consists of mainlines and laterals (mostly plastic pipe) buried below the depth of normal field operations. Only the sprinklers and a portion of the risers are above the ground surface.

To irrigate the field, one or more zones of sprinklers are cycled on or off with a control valve at the mainline. Opening and closing of valves can be manual, programmed electronically, or timer clock controlled. 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, dust control, and chemical application.

A diamond or triangular pattern for sprinkler head layout is recommended for solid set systems, thereby improving application uniformity.

2) Periodic Move Sprinkler Systems

A periodic move sprinkler system is set in a fixed location for a specified length of time to apply a required depth of water. This is known as the irrigation set time. After an irrigation set, the lateral or sprinkler is moved to the next set position. Applications range from 50% - 75%.

Hand Move Lateral Systems

Hand move portable aluminum lateral systems are a common system used in New Jersey for vegetable, orchard, and field crops. Aluminum laterals are moved by hand between irrigation sets. Lateral sections are typically 20, 30, or 40 feet long. The mains may be portable above ground or permanent buried mains. Riser height must be based on the maximum height of the crop to be grown. Minimum height is generally 6 inches, and risers over 4 feet in height must be anchored or stabilized. Lateral size is either 3 inch or 4 inch. Due to the ease of carrying from one set to the next, 3 inch is preferred. However for long lateral lines, 4 inch aluminum should be used to keep velocity under 5 feet per second and maintain pressure losses below 20 percent of the design pressure. Hand move lateral systems have the lowest initial cost, have the highest labor requirement, and are easily adapted to irregular fields. Application efficiencies can be 60 – 75 percent with proper management.

Side Roll System

A Side roll system is similar to a hand move system except that the wheels are mounted on the lateral. The lateral pipe serves as an axle to assist in moving the system sideways by rotation to the next set. Each pipe section is supported by a large diameter wheel (at least 3 ft) generally located at the center but can be at the end. Wheel diameters should be selected so that the lateral clears the crop. The lateral pipe itself forms the axle for the wheels. A flexible hose or telescoping section of pipe is required at the beginning of each lateral to connect on to the mainline outlet valves. Rigid couplers permit the entire lateral, up to 1/4 mile long, to be rolled forward by applying power at the center or the end while the lateral pipe remains in a nearly straight line. Normally, the drive unit contains a gasoline engine and a transmission with a reverse gear. Self righting or vertical self aligning sprinkler heads are used because the sprinkler head is always upright. Without the self aligning heads, extra care must be taken so that the pipe rotation is fully complete for the full length of the lateral, and all sprinkler heads are upright. Poor distribution uniformity results if the sprinkler heads are not upright. Lateral diameters of 4 or 5 inches are most common and sprinkler head spacing 30 or 40 feet. Laterals can be up to 1600 feet long with one power unit. Quick drain valves are installed at several locations on each lateral to assist line drainage before it is moved since the lateral moves much easier when it is empty. Minimum operating pressure must not drop below 24 psi for drains to properly close and seal. Empty laterals must b anchored to prevent movement by wind. Side roll systems have a low labor requirement, but they have higher initial and maintenance costs than hand move lateral systems. They irrigate a rectangular area. They are not adapted to tall crops. Topography must be flat or gently rolling. With proper management, application efficiencies can be 60 – 75 percent.

Gun Type Sprinkler (Stationary)
Large, periodic move, gun type sprinklers are operated as a large single impact type sprinkler head. The sprinkler is moved from one set to the next either by hand or a small tractor depending on the size or whether they are towable. Generally, only one sprinkler is operated pr lateral. Lateral lines are usually aluminum pipe with quick-coupled joints. Nozzle sizes are large and can vary between ½” to 1 ¾”. Operating pressures can range from 50 psi to 120psi with flow rates at 50 to 1000 gallons per minute. When irrigating, the sprinkler is allowed to remain at one location (set) until the desired amount of water is applied. Application rates can be very high and uniformity of application can be adversely affected with wind speed greater then 4mph. Droplet size will be large beyond 50 feet of the sprinkler, resulting in soil puddling and damage to sensitive crops. With proper management application efficiency can be 50 –60 percent.

Planning and design procedures:
For both fixed and periodic move systems refer to National Irrigation Guide page 6-31 to 6-33; and NEH, Part 623 (Section 15) Chapter 11, Sprinkle Irrigation.

3) Continuous (Self) Move Sprinkler System

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. This system irrigates a circular field unless end guns and swing lines are cycled on in corner areas to irrigate more of a square field. 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 drives 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 higher discharge, part circle gun is generally used at the extreme end (end gun), of the lateral to irrigate the outer fringe of the lateral. Each tower which is generally mounted on rubber tires, has a power device designed to propel the system around the pivot point. The most common power units include electric motor, hydraulic water drive, and hydraulic oil drive. Towers are spaced from 80 to 250 feet apart, and lateral lengths vary up to ½ mile. Long spans require a substantial truss or cable to support the lateral pipe in place. Use of the center pivot is growing rapidly in the southwestern and central part of New Jersey. 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 expands 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, discharge flow in all other

heads 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 then adequate maintenance in corner systems operating all the time, total field application uniformity is reduced even further. Many techniques have been developed to reduce energy used, lower system flow capacities, and maximize water use efficiency. These include using Low Energy Precision Application (LEPA) and Low Pressure In-Canopy (LPIC) systems. LEPA systems (precision application) require adequate (implemented) soil, water and plant management. LPIC systems are used on lower value crops where localized water translocation is acceptable, (30 feet ahead of or behind the lateral position). Water is applied within the crop canopy through drop tubes fitted with low pressure 5 – 10 psi application devices near the ground surface. Good soil and water management are required to obtain application efficiencies in the high 80's. LPIC systems are not suitable for use on low intake soils.

In New Jersey most center pivot systems are low pressure, low volume systems with sprayheads or rotator heads on drops. Each sprinkler has a pressure regulator set at 10 – 20 psi.

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.

Advantages:

- Reduced operating labor
- High water application uniformity with good water management
- Light frequent applications can be made; systems with nozzle pressures as low as 10 psi can be used
- Chemical applications can be made
- Pivots can operate as part circle systems because they are capable of operating either in forward or in reverse

Limitations:

- Field corners are not irrigated unless special corner arms are used to fill in the corners, or other systems are used
- High application rates at the outer end of the center pivot lateral can cause runoff and erosion where adequate soil surface storage is not provided.
- Soil surface compaction may increase toward the outer edge of the circle.
- With light applications there is an increase in potential water evaporation losses. Therefore, more intense soil moisture management must be taken to prevent soil moisture shortages.
- Drive wheels may cause ruts in some soils.
- Topography should be uniform with slopes of not more than 10 percent. Undulating topography produces more runoff and drive problems.
- High initial costs and maintenance costs with corner arm systems.

Planning and design considerations:
An irrigation equipment dealer can use a computer program provided by each center pivot system manufacturer to perform a detailed design specific for that make and model of pivot. Since sprinkler pipe size and head spacing combinations are unique for each manufacturer, this is the only way accurate, detailed designs can be prepared. The farmer is generally provided 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.

As a service to the cooperator, NRCS can review pivot designs prepared by others to assure the proposed application provides adequate water to satisfy the needs of the crop(s), match the available water capacity of the soil, and that it does not have negative impacts on field or farm resources such as soil erosion, offsite sedimentation, and pollution of surface and ground water.

Refer to NEH, Part 623 (Section 15), Chapter 11, Sprinkle Irrigation for detailed design procedures, and National Irrigation Guide, Chapter 6, for additional planning and design considerations.

Linear Move Sprinkler System

A linear move sprinkle system is a continuous, self moving, straight lateral that irrigates a rectangular field. It is similar to the center pivot in that the lateral is supported by trusses, cables, and towers mounted on wheels. Most linear move systems are driven by electric motors located in each tower or are hydraulic driven. A self aligning system is used to maintain near straight line uniform travel. One tower is the master control tower for the lateral where the speed is set, and all other towers operate in start-stop mode to maintain alignment. A small cable mounted 12 to 18 inches above the ground surface along one edge or the center of the field guides the master control tower across the field.

Linear move systems can be equipped with a variety of sprinkle or spray heads. Drop tubes and low pressure spray heads located a few inches above the ground surface or crop canopy can be used instead of sprinkler heads attached directly to the lateral. To conserve water and energy, the low pressure sprinkle heads on drop tubes are preferred for linear move systems in New Jersey. Linear move systems are similar to center pivot as they are also used as LEPA and LPIC. With these methods surface storage (residue or small basins) must be available throughout the irrigation season to prevent runoff due to the high application rates.

With proper management, application efficiencies are similar to the center pivot system.

Linear move systems are high cost and generally used on medium to high value crops and multiple crop production areas.

Advantages:

- The entire field is irrigated.
- High application uniformity because the laterals are nearly continuously moving.
- Chemigation can be practiced.

Limitations:

- High initial and annual operating costs.
- The need to supply water to the moving lateral.
- When the irrigation is complete (laterals reach the end of the field), the laterals must be moved back to the starting position or moved endwise to an adjacent field. When moving the lateral endwise, tower wheels must be rotated 90 degrees or be placed on individual tower dollies.

Planning and design considerations:

Refer to NEH, Part 623 (Section 15), Chapter 11, Sprinkle Irrigation, and National Irrigation Guide, Chapter 6 for details concerning design. Manufacturers' technical data should be consulted for additional up to date information. Also use NJ Planning and Design Worksheets and Excel Design Spreadsheet for Linear Move system design, located in Chapter 15, NJ Irrigation Guide.

Traveling Gun Sprinkler
A traveling gun system (traveler, gun, big gun), consists of a high capacity single nozzle sprinkler mounted on a chassis to which a flexible hose, usually 3 to 5 inches in diameter and up to 1320 feet long, is connected. There are three general types of traveling gun sprinklers. These are cable reel, hose reel, and self–powered/propelled.

With a traveling gun system, the gun is mounted on a 4-wheel chassis and is pulled along selected travel lanes by a cable or the hose wrapping on a rotating reel. The reel or winch can be powered by a water turbine, water piston, or engine drive and reels in the anchored cable or hose through the field in a straight line.

Application depth is regulated by the speed at which the hose or cable reel is operated or by the speed of the self-contained power unit. As the traveler moves along its path, the sprinkler wets a strip of land 200 – 400 feet wide. After the unit reaches the end of the travel path, it is moved and set to water an adjacent strip of land. The overlap of adjacent strips depends on the distance between the travel paths, wetted diameter of sprinkler, average wind speed, and application pattern of the sprinkler. After one travel path (towpath) is completed, the sprinkler is reset by towing it to the edge of the field. Refer to Figure NJ 6.1 for typical traveling gun system layout.

Sprinkler discharge flows can range from 50 to more then 1,000 gallons per minute with nozzles ranging from 0.5 to 1.75 inches in diameter and operating pressure from 69 to 120 psi. Refer to Table NJ 6.2 for typical discharges and wetted diameters for gun type sprinklers with 24 degree angle of trajectory and tapered nozzles operating with no wind.

Advantages:
- Odd shaped fields can be irrigated with automated equipment.
- Minimum manual labor.
- Suited to sandy soils or high intake rate soils.
- Well adapted to tall crops such as corn.
- Suitable for irrigating several different fields in a crop rotation.

Limitations:
- Traveling gun sprinklers require high operating pressures and high power pumping units.
- Unsuitable for low intake rate soils or soils that tend to surface seal as a result of puddling.
- Turbine powered winches require additional water pressure resulting in an increased energy demand and high cost. Systems need to be sized for high pressure (friction losses can be significant if hose sizes are not large enough). Typically hose sizes are reduced to keep the cost down. Decreased capital cost is a trade-off for increased energy cost. An energy cost analysis should be made.
- With large droplet sizes, surface compaction and runoff are problems as well as crop damage.
- Water is often applied to non-cropped areas in attempts to adequately irrigate field edges.
- Application efficiency and distribution uniformity is low due to wind, high evaporation, and runoff losses.

Planning and design considerations:
In addition to the high operating pressure required at the sprinkler nozzle, hose pressure losses can add another 20 – 40 psi to the total dynamic head required at the pump. This needs to be considered when designing the

delivery system to meet crop water requirements. Sometimes a booster pump will be necessary in the field to increase pressure that is lost through the hose or turbine. Refer to Table NJ 6.3, for friction losses in flexible irrigation hose used on traveling gun systems; and Table NJ 6.4, for guidelines for sizing traveling gun hoses.

Since wind speed adversely affects distribution uniformity with traveling gun systems, a gun system should be designed for 5mph or less wind speed. Refer to Table NJ 6.5, for recommended maximum travel lane spacing as a function of wetted diameter and average wind speed; and Table NJ 6.6 for gross depth of water applied.

Power requirements to drag a hose depend on the size of the hose, soil moisture conditions, and crop. Energy requirements to pull the hose are greatest on wet, bare, sticky soils, and less on vegetated towpaths or bare sandy soils. Excessive wear to the hose can occur on soils containing sharp or abrasive rock fragments.

Refer to NEH, Section 623 (Section15), Chapter 11, Sprinkle Irrigation, for detailed explanation of design procedures and example. Also use NJ Planning and Design Worksheets and Excel Design Spreadsheet for Traveling Gun System design, located in Chapter 15, NJ Irrigation Guide.

Traveling Boom Sprinkler Systems

A traveling boom system is similar to a traveling gun except several nozzles are used. These systems have higher distribution uniformity than traveling guns for the same diameter of coverage. They are not as popular in NJ as the traveling gun system; however, do provide options when a grower prefers a lower volume and pressure systems to reduce the high energy costs associated with a traveling gun system. The boom can be designed with low pressure and low flow nozzles that operate at higher efficiency and uniformity.

The traveling boom usually is rotated by back pressure from fixed nozzles, or may be fixed. It is typically moved by a self-contained continuously moving power unit by dragging or coiling the water feed hose on a reel. A boom can be nearly 100 feet long with uniformly spaced nozzles that overlap (similar to a linear move lateral).

Advantages:
- Lower energy requirement then traveling gun.
- Higher uniformity then traveling gun.
- Can be fabricated locally in any good farm machine shop.
- Labor saving after initial installation.
- Better on high value specialty crops then traveling gun (more efficient delivery).

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

Figure NJ 6.1 Traveling gun type sprinkler system layout

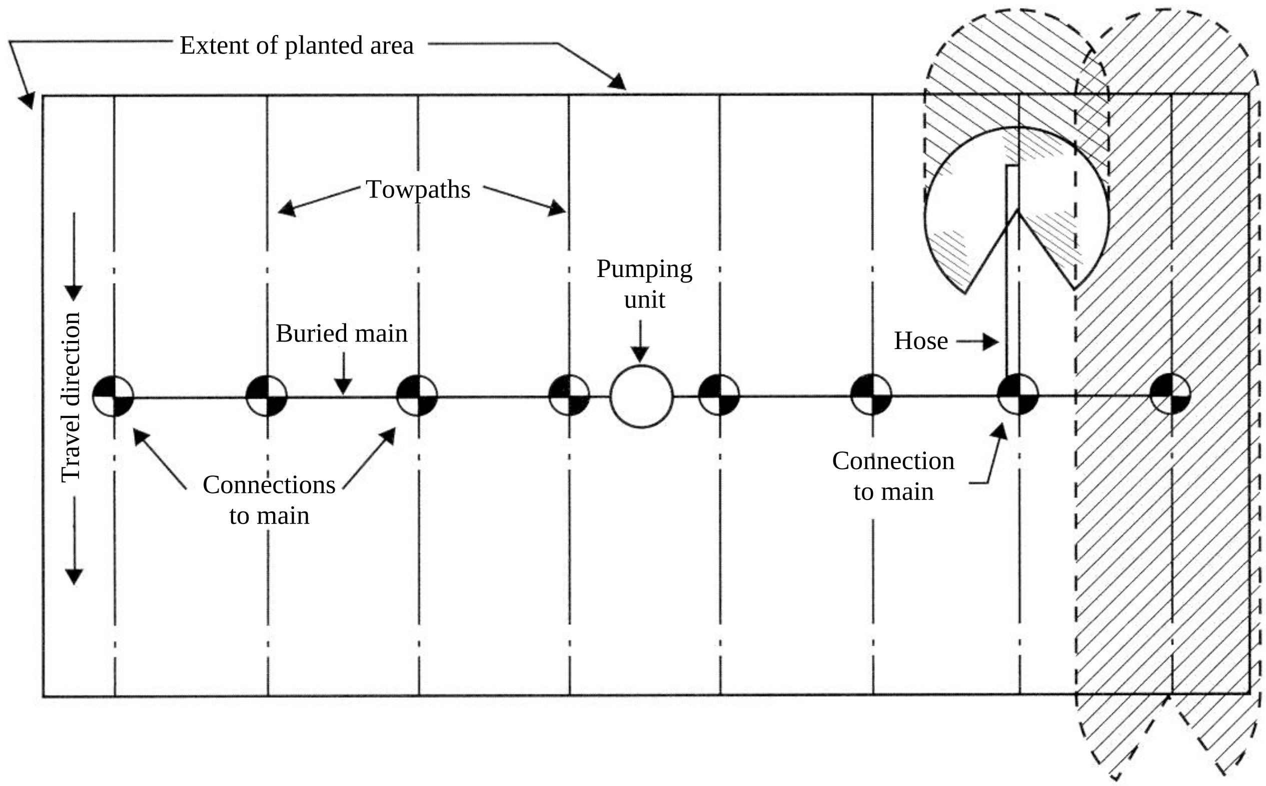

Table NJ 6.2 Typical discharge and wetted diameters for gun type sprinklers with 24° angles of trajectory and tapered nozzles operating when there is no wind

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

Table NJ 6.3 Friction loss in flexible irrigation hose used on traveling gun type sprinkler system

Flow (gpm)	Friction Loss (lb/in^2/100 ft) hose size(in)					
	2 1/2	3	3 1/2	4	4 1/2	5
	lb/in^2 per 100 ft					
100	1.6	0.7	0.3			
150	3.4	1.4	0.7			
200	5.6	2.4	1.4	0.6		
250		3.6	1.9	0.9		
300		5.1	2.3	1.3	0.6	
400			2.6	2.3	1.3	
500			3.5	3.5	2.1	1.1
600				4.9	2.7	1.6
700					3.6	2.1
800					4.6	2.7
900						3.4
1000						4.2

Table NJ 6.4 Guidelines for sizing traveling gun type sprinkler hoses

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

Table NJ 6.5 Maximum travel lane spacing for traveling gun type sprinklers as a function of wetted diameter and wind speed

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

Table NJ 6.6 Gross depth of water applied for continuous moving large gun type sprinkler heads[1/]

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

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

c) Sprinkler System Design

Design Procedure

A step-by-step checklist of the procedure normally used in planning a sprinkler irrigation system follows. Some of these steps are discussed in more detail in the NRCS National Engineering Handbook, Section 15, Sprinkler Irrigation.

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

Step 2. Make an inventory of available resources and operating conditions. Include information on soils, topography, water supply (quantity and quality), source of power (type and location), crops, irrigator's desire for a type of sprinkler system, labor availability, farm operation schedules, and water management skills.

Step 3. Determine soil characteristics and limitations. Include AWC, maximum allowable application rates (Maximum rates are obtainable from Table NJ 2.1), usable rooting depth, acidity, salinity, and water table. Crop rooting depth needs to be identified for specific fields and soils. A field investigation is strongly recommended. If a field contains more than one soil, the most restrictive soil must be determined.

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

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

Step 6. Determine alternative irrigation systems suitable to the site and desired by the user. Evaluate alternative irrigation systems with user, and their multi-resource impacts on the environment.

Step 7. Determine sprinkler spacing, nozzle sizes, head type, discharge, operating pressure, wetted diameter, average application rate, and performance characteristics.

Step 8. Determine number of sprinklers in an irrigation set (zone) required to meet system capacity requirements; number of laterals needed for a selected time of set; set spacing; moves per day; and frequency of irrigation in days.

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

Step 10. Make necessary adjustments to meet layout conditions so the system fits the field, soils, crops, water supply, environmental concerns, and the desires of the irrigation decision-maker.

Step 11. Finalize sprinkler irrigation system design, layout, and management skills required by then irrigation decision maker.

Step 12. Determine lateral size(s) based on number of heads, flow rate, pipeline length, and allowable pressure loss differential between the first and last sprinkler head. Determine if pressure or flow regulators are needed. Determine minimum operating pressure required in mainline(s) at various critical locations on the terrain.

Step 13. Determine mainline sizes required to meet pressure and flow requirements according to number of operating laterals.

This includes diameter, pipe material, mainline location, and type of valves and fittings. It involves hydraulic calculations, basic cost-benefit relationships, and potential pressure surge evaluations for pipe sizes and velocities selected. Mainline operating pressure measured at the discharge side of each lateral outlet valve, should be within 10 percent of the design lateral operating pressure. Check main line pipe sizes for power economy. Compare pumping cost versus pipe size initial cost on annual basis. Refer to National Engineering Handbook, Section 15, Irrigation.

Step 14. Determine maximum and minimum Total Dynamic Head (TDH) required for critical lateral location conditions. Determine total accumulated friction loss in mainline, elevation rise (drip) from pump to extreme point in the fields, water surface to pump impeller (lift), column loss with vertical turbine pumps, and miscellaneous losses (fittings, valves, elbows) at the pump and throughout the system.

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

Step 16. Select pump and power unit for maximum operating efficiency within range of operating conditions. Use pump performance curves prepared for each make and model of pump. Every pump has a different set of performance (characteristic) curves relating to operating head (pressure) output and discharge capacity. Select pumps and power units for maximum operating efficiency within the full range of expected operating conditions. Only pump capacity and TDH requirements are recommended to be provided to the user. Never select a pump based on horsepower alone. Let a pump dealer select the appropriate motor or engine and pump to fit the conditions. Availability of a pump dealer for providing maintenance and repair should be considered by the operator. Buying a used pump without first checking pump characteristic curves for that specific pump is seldom satisfactory. A pump needs to match the required capacity and TDH for efficient and economic performance. An inefficient operating pump can use needless excess energy.

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

In New Jersey irrigation system designs and components are usually prepared by an irrigation system design consultant or equipment dealer. Regardless of who does the design, the processes listed in steps 1 to 17 should be followed to provide an adequate system suitable to the site.

Design procedures and examples are provided in more detail in NEH, Part 623, (Section 15), Chapter 11, Sprinkle Irrigation. Manufacturer literature is readily available and most useful in selection of sprinkler head models, nozzle sizes, and discharge at various pressures. New Jersey planning and design worksheets should be used to complete this process. Refer to NJIG Chapter 15, Tools and Worksheets, for blank worksheets.

Lateral-Line Design

Layout of the system will be determined by location of the water supply, the convenience of moving operations, and field cultural practices. Problems which can be resolved through trial and error on paper are much less costly to remove before the system is installed. Careful consideration and discussions of the system operations while using a layout map can assist in visualizing each step of the proposed operation. The owner's knowledge of the land and operation methods can be combined with the designer's knowledge of irrigation systems to produce an irrigation system which best suits the owner's needs and which will yield the greatest returns with least effort.

Certain considerations should be kept in mind to arrive at desirable layouts:

1. The laterals, if possible, should be laid across the prevailing slope or as nearly level as possible.

2. Where the laterals must be laid uphill, elevations that produce variations of pressure greater than ten percent of operating pressure should be avoided.

3. Laterals laid downhill have certain advantages, particularly where pipe size reduction or control valves can be used to equalize pressure.

4. For ease of moving, hand-moved laterals should be kept to four inches in diameter or less.

5. If possible, sprinkler laterals should be laid perpendicular to the direction of prevailing winds.

6. Sprinkler laterals of equal length are desirable.

7. The increased cost of an extra lateral (per unit system) is often justified because it allows for dry moves, convenience in moving time, and equalized pressure conditions.

8. In many instances, the use of smaller nozzles to reduce the gallonage per sprinkler, with a corresponding increase in time for each set, will allow the addition of a lateral to balance the system, and will often allow smaller pipe sizes to be used.

9. If a choice exists, locating the water source and pump in the center of the area to be irrigated is usually most desirable.

Sprinkler System Capacity Requirements

Table NJ 6.7 is useful in determining the capacity requirements for a sprinkler system. This table shows the number of gallons per minute per acre required for a twenty-four hour per day operation. For twelve hours of operation per day, the values in this table should be multiplied by 2. For eight hours of operation per day, they should be multiplied by 3. For other lengths of operation per day, multiply the table values by the number of times the hours of operation can be divided into 24.

These values should then be converted to gross water applied by dividing the gallons per minute by the efficiency percentage expressed as a decimal fraction. Overall sprinkling efficiencies average from 60 percent in hot, dry climates to 80 percent in cool, humid climates.

<u>Example</u>: For a sprinkling frequency of ten days, three net inches of water required for plant use, twenty-four hour per day operation, and 70 percent efficiency of application, Table NJ 6.7 shows 5.65 gallons per minute which will, when divided by the percent efficiency,

equal eight gallons per minute gross requirements per acre.

5.65 / 0.70 = 8 gpm

On a 12-hour operation per day basis:

$\frac{24}{12}$ x 5.65 / 0.70 = 16 gpm per acre

The values shown in Table NJ 6.8 convert any given flow in gallons per minute per acre to acre inches delivered in a given time period. This table is valuable in checking the adequacy of any sprinkling system to meet the overall irrigation requirements.

TABLE NJ 6.7

Gallons per minute per acre required to apply a given number of inches of water for different frequencies of irrigation, twenty-four hours per day operation.

Frequency	INCHES OF WATER PER IRRIGATION							
Days	1	2	3	4	5	6	7	8
1	18.8	37.6	56.5					
2	9.4	18.8	28.3	37.7				
3	6.3	12.6	18.8	25.1				
4	4.7	9.4	14.2	18.8	23.5			
5	3.8	7.5	11.3	15.0	18.8			
6	3.2	6.3	9.4	12.6	15.7	18.8		
7	2.69	5.4	8.1	10.8	13.4	16.1	18.8	
8	2.36	4.7	7.0	9.4	.11.7	14.1	16.5	18.8
9	2.10	4.2	6.3	8.4	10.5	12.6	14.7	16.8
10	1.88	3.76	5.65	7.54	9.4	11.3	13.2	15.0
12	1.57	3.14	4.70	6.27	7.85	9.4	10.9	12.5
14	1.35	2.69	4.04	5.38	6.23	7.54	9.4	10.8
16	1.18	2.36	3.54	4.70	5.90	7.06	8.3	9.4
18	1.05	2.10	3.15	4.20	5.25	6.30	7.35	8.4
20	0.94	1.88	2.83	3.77	4.71	5.66	6.60	7.5
22	0.86	1.7	2.6	3.4	4.3	5.1	6.0	6.9
24	0.78	1.6	2.4	3.1	3.9	4.7	5.4	6.2
26	0.72	1.5	2.2	2.9	3.6	4.3	5.0	5.7
28	0.67	1.4	3.0	2.7	3.4	4.0	4.7	5.4
30	0.63	1.3	1.9	2.5	3.1	3.7	4.4	5.0

Gallons per minute are directly proportional to inches applied and inversely proportional to frequency of irrigation in days.

TABLE NJ 6. 8

Conversion from Gallons per Minute per Acre to Acre Inches

Flow in G.P.M. per Acre	ACRE INCHES DELIVERED IN 1 day	1 week	1 month
1.0	0.05	0.37	1.6
1.5	0.08	0.56	2.4
2.0	0.11	0.74	3.2
2.5	0.13	0.93	4.0
3.0	0.16	1.12	4.8
3.5	0.19	1.30	5.6
4.0	0.22	1.46	6.4
4.5	0.24	1.67	7.2
5.0	0.27	1.86	7.9
5.5	0.29	2.04	8.7
6.0	0.32	2.22	9.5
6.5	0.34	2.41	10.3
7.0	0.37	2.60	11.1
7.5	0.40	2.78	11.9
8.0	0.42	2.97	12.7
8.5	0.45	3.16	13.5
9.0	0.48	3.34	14.3
9.5	0.50	3.52	15.1
10.00	0.53	3.71	15.9

Inches delivered are directly proportional to time, and to flow.

Table NJ 6.9 WATER APPLICATION EFFICIENCIE5 FOR WELL PLANNED SPRINKLER SYSTEMS (PERCENT)[1]

Depth of Water Applied per Irrigation (acre-inches per acre)	Application rate (inches per hour) Under 0.5	More than 0.5
	Average wind movement, 0-4 miles per hour	
Under 2.0	65	75
More than 2.0	70	75
	Average wind movement, 4-10 miles per hour	
Under 2.0	60	65
More than 2.0	65	70
	Average wind movement, 10-15 miles per hour	
Under 2.0	55	60
More than 2.0	60	65

1/ Use efficiencies 5 percent higher than shown for areas where peak consumptive use rates are less than 0.20 inch per day and for undertree irrigation in all areas.

Nozzle Size and Capacity

The soil infiltration rate limits the application rate and will affect the selection of the proper sprinkler, nozzle sizes, flow rates, pressure, and sprinkler spacing. The application rate is determined by the nozzle size and pressure at given spacing. The discharge requirements of the sprinkler determine the sprinkler size to use.

When the application rate and spacing have been determined, the required sprinkler capacity can be calculated by the formula:

$$q = \frac{S_m S_1 r}{96.3}$$

q = discharge from each sprinkler (gpm)

S_m = spacing of laterals on the main (feet)

S_1 = spacing of sprinklers on the laterals (feet)

r = application rate (inches per hour)

Figure NJ 6.1 solves this equation.

If the spacing selected is 40 x 50 feet and the application rate is 0.48 inch per hour, the required sprinkler discharge will be 10 gpm.

When the nozzle sizes and sprinkler spacing and operating pressures (Pa) have been determined, alternative layouts can be tried to select the one which best meets the need of the operator. For example, application of 2.8 inches of water in a seven-hour set requires an application rate of 0.40 inch per hour (2.8 / 7 = 0.4). Figure NJ 6.1 shows that this can be accomplished on a 30 x 40 feet spacing using a 4.99 gpm sprinkler or on a 40 x 60 feet spacing using a 9.98 gpm sprinkler, etc.

Each type of sprinkler has certain moisture-distribution pattern characteristics that change as nozzle size and operating pressure (Pa) change. Each has an optimum range of operating pressures for each nozzle size.

For a given sprinkler discharge and nozzle size, the range of operating pressures produces the following effects:

- At the lower side of the specified pressure range for any nozzle, the water is broken up into larger drops. When pressure falls too low, the water from the nozzle falls in a ring a distance away from the sprinkler, thus giving a poor moisture-distribution pattern.
- On the high side of the pressure range, the water from the nozzle breaks up into finer drops and settles around the sprinkler. Under such conditions, the pattern is easily distorted by wind movement.
- Within the desirable range, the sprinkler should produce reasonably uniform distribution of water.

For a given pressure, larger drops are obtained from a large nozzle size and fine spray from a small nozzle. All manufacturers of revolving sprinklers recommend operating pressures or ranges of pressures for each type of sprinkler and nozzle size that will result in the most desirable application pattern.

Sprinkler performance tables, such as Table NJ 6.10, show that a 1/8” x 3/32" sprinkler will discharge 5.02 gpm at 50 psi and a 3/16” x 1/8” sprinkler will discharge 10.10 gpm at 45 psi. Other sprinklers with equivalent discharge rates could be selected. The selection should be made in accordance with the manufacturer's recommendations for safe ranges and operating pressures and nozzle sizes for best results.

Because the variety of choices in sprinklers and nozzles can be adjusted to a range of spacing, other considerations, such as wind, uniform coverage, farm operations, economic pipe sizes, the number of lateral lines, and total labor needed, may play the dominant role in the selection of the final spacing

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FIGURE NJ 6.2 SPRINKLER DISHARGE RATES FOR COMMON SPACING AND APPLICATION RATES

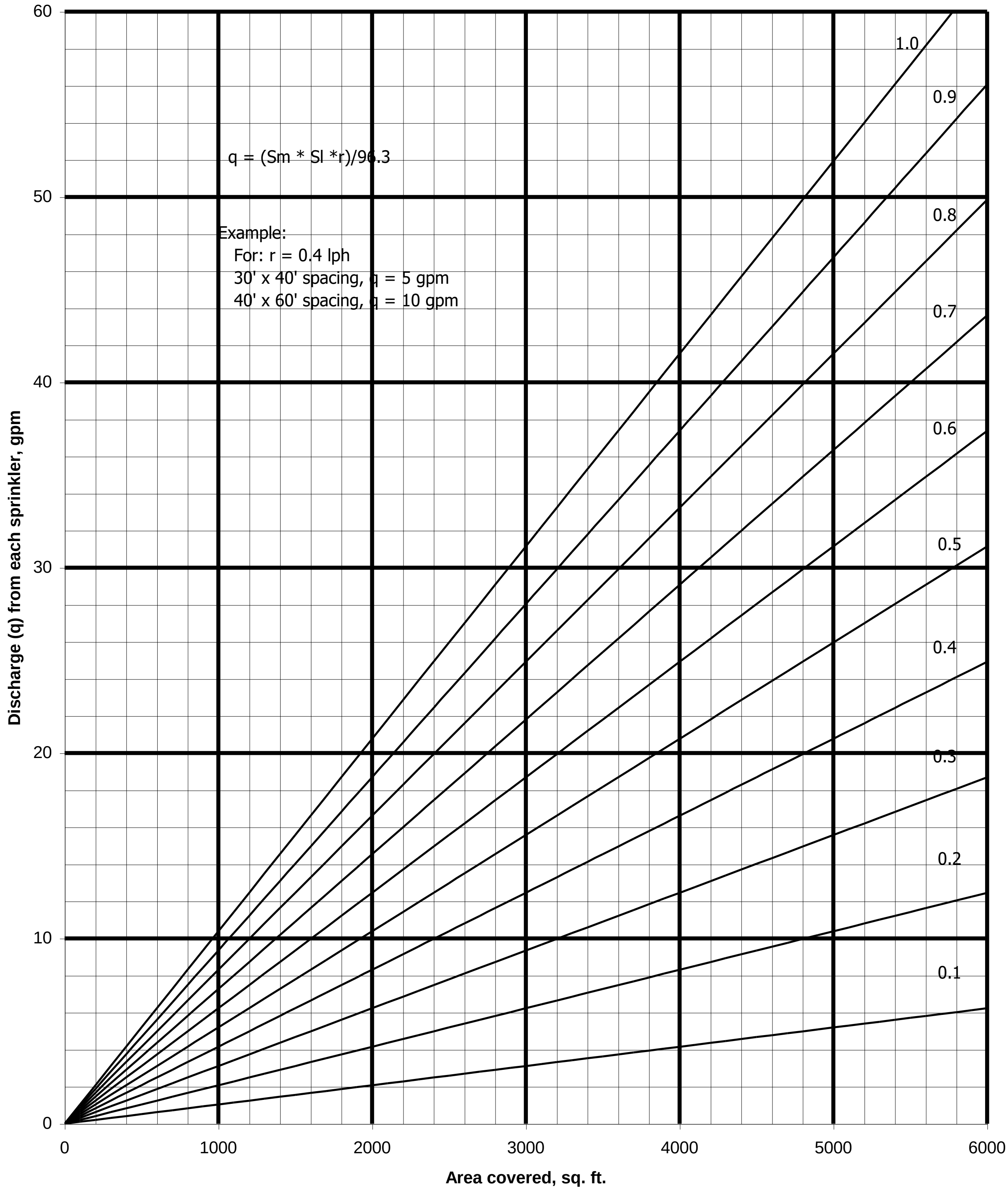


TABLE NJ 6.10 PERFORMANCE DATA OF TYPICAL SPRINKLERS

Check manufacturer's catalog for specific nozzle characteristics.

Nozzle	PSI	GPM	Wetted Diameter (ft)
1/8"	30	2.5	74
	35	2.7	75
	40	2.9	76
	45	3.1	77
	50	3.2	78
	55	3.4	79
	60	3.6	80
5/32"	45	4.7	89
	50	5.0	90
	55	5.2	91
	60	5.4	92
	65	5.7	93
	70	5.9	94
11/64"	45	4.7	89
	50	6.0	95
	55	6.3	96
	60	6.6	97
	65	6.8	98
	70	7.1	99
3/16"	45	6.8	98
	50	7.2	100
	55	7.5	101
	60	7.8	102
	65	8.2	103
	70	8.5	104

TABLE NJ 6.10 PERFORMANCE DATA OF TYPICAL SPRINKLERS (cont.)

Check manufacturer's catalog for specific nozzle characteristics.

Nozzle	PSI	GPM	Wetted Diameter (ft)
13/64"	45	8.1	111
	50	8.5	113
	55	8.9	115
	60	9.2	116
	65	9.5	117
	70	9.8	118
7/32"	45	9.4	123
	50	9.9	125
	55	10.4	127
	60	10.9	129
	65	11.4	131
	70	11.8	134
1/4"	50	12.9	124
	55	13.6	126
	60	14.2	128
	65	14.8	130
	70	15.4	132
	75	16.0	134
9/32"	55	17.0	140
	60	17.9	143
	65	18.7	146
	70	19.5	150
	75	20.3	153
	80	21.1	157

TABLE NJ 6.10 PERFORMANCE DATA OF TYPICAL SPRINKLERS (cont.)

Check manufacturer's catalog for specific nozzle characteristics.

Nozzle	PSI	GPM	Wetted Diameter (ft)
3/8”	70	33.3	175
	75	34.5	178
	80	35.7	181
	85	37.0	184
	90	38.3	187
	95	39.5	194
	100	40.7	196
1/2”	80	61.6	201
	85	63.5	204
	90	65.3	207
	95	67.1	209
	100	68.9	211
1/8” x 3/32”	40	4.49	81
	45	4.77	82
	50	5.02	83
	55	5.27	84
	60	5.51	85

TABLE NJ 6.10 PERFORMANCE DATA OF TYPICAL SPRINKLERS (cont.)

Check manufacturer's catalog for specific nozzle characteristics.

Nozzle	PSI	GPM	Wetted Diameter (ft)
3/16” x 1/8”	45	10.10	98
	50	10.60	100
	55	11.10	101
	60	11.60	102
	65	12.00	103
	70	12.40	104
	75	12.80	105
1/4” x 3/16”	55	21.1	136
	60	22.0	139
	65	22.9	142
	70	23.8	145
	75	24.7	148
	80	25.5	151
3/8” x 7/32”	70	44.9	166
	75	46.7	169
	80	48.3	172
	85	49.8	175
7/16” x 7/32”	75	57.9	181
	80	60.0	184
	85	62.0	187
	90	63.9	190
	95	65.8	192
	100	67.5	194
1/2” x 1/4”	80	78.	195
	85	80.	198
	90	82.	201
	95	85.	203
	100	87.	205

Wind Effects

Wind affects the spacing of sprinklers on the laterals and the spacing of laterals along the main. The higher the wind velocity the closer must be the sprinkler spacing on the lateral and the lateral spacing on the main. If the wind is moving diagonally through the system, a square pattern, such as 40 x 40 feet or 60 x 60 feet, will give a more uniform precipitation pattern. Since it is customary to place the lateral at right angles to the wind direction, it is simpler to space the sprinklers more closely, such as in 30 x 40 feet or 40 x 60 feet patterns, than to move the lateral lines.

The effect of wind on sprinklers is generally as follows:

Wind Conditions	Effective Diameter of Sprinkler
0-6 mph	60%
6-10 mph	50%
10 or more mph	40% or less

Operating Pressure

Pressure increases cause more breakup of the nozzle stream and, within reasonable limits, produce more uniform sprinkler patterns. Break-up of stream nozzles for various sizes of sprinklers can be accomplished as follows:

Nozzle Sizes	Adequate Break-up	Optimum Break-up
1/8”-11/64”	30 psi	40-50 psi
3/16”-15/64”	40 psi	50-60 psi
1/4”-3/8”	50 psi	60-70 psi

Single-nozzle sprinklers require about 5 psi more than the value shown for two-nozzle sprinklers to produce a good pattern.

Application Pattern

The sprinkler application pattern should be field checked periodically. The application pattern variation in most patterns is at least 0.1 inch from the average precipitation rate. At rates over 0.4 inch per hour, the variation will normally be 25 percent of the average rate on either side of the mean. Spacings and nozzles which produce less than 0.18 inch per hour should be avoided. Rates in excess of 0.5 inch per hour are likely to produce poor patterns and cause leaching and runoff.
Longer sets will usually produce more uniform patterns. Staggered spacings and lateral moves can equalize precipitation deficiencies in the pattern. Pin arrangements and nozzle broaching to break up the nozzle stream will reduce the effective wetted diameter of the nozzle.

Capacity of the Lateral

Multiplying the number of sprinklers on a lateral line by the sprinkler discharge (gpm) at average operating pressures will give the lateral capacity, which is then used in determining the pipe size required for the lateral line. Adding the capacities of all laterals will give the peak requirements (gpm) for the main line.

Pressure Losses

Pressure loss in a pipe is determined by the rate of flow (gpm) for a given distance in feet through the selected pipe. These losses are important in sprinkler system design. The sprinkler operating pressure is equal to the pump operating pressure minus losses in the distribution system to friction and plus or minus the elevation differences converted to pressure (2.31 ft. or 0.740 m = 1 psi).

Flow characteristics in pipes vary according to the smoothness of the pipe interior. Three different formulas are commonly used to determine pipe carrying capacities and pressure losses. The Hazen-Williams equation uses a “C” factor which varies from 150 for very smooth pipe, such as PVC, to 60 for a pipe with a very rough interior, such as old steel pipe. The Scobey equation uses a "Ks" factor, while the Manning equation uses an “n” factor.

Table NJ 6.11 shows pipe friction losses for various rates of flow and pipe diameters for PVC or ABS compound and aluminum pipe.

Life expectancy of the pipe, power requirements for pumping, ease of installation, and maintenance costs should be considered in selecting pipe for the system. Other local conditions should also be included in pipe evaluations by the designer.

In computing friction losses for a system with a number of laterals, only the lateral with the greatest loss need be considered in the summary of losses for the system.

Example: A system has a main supply line which carries 1500 gpm and serves six 4-inch laterals spaced at 80 feet, with each lateral requiring 250 gpm and having ten 25.0 gpm sprinklers spaced 60 feet apart. The sprinklers require an operating pressure (Pa) of 70 psi.

Using Table NJ 6.11 , determine friction losses for 20-foot sections of portable aluminum pipe and PVC pipe equal to 100 feet of lateral and convert to pressure loss.

For 4-inch, 20-foot sections portable aluminum:

From Table NJ 6.11:
For Q = 260 gpm, H_f = 4.400 feet per 100 feet
For Q = 240 gpm, H_f = 3.779 feet per 100 feet
Length factor (footnote 1) = 1.07

For Q = 250 gpm:

H_f = ((4.400 - 3.779) x 10/20 + 3.779) x 1.07
= 4.376 feet per 100 feet
Pressure loss = 4.376 feet x 0.433 psi/foot
= 1.89 psi per 100 feet

For 4-inch PVC:

From Table NJ 6.11:
For Q = 260 gpm, H_f = 3.10 feet per 100 feet
For Q = 240 gpm, H_f = 2.67 feet per 100 feet

For Q = 250 gpm:
H_f = (3.10 - 2.67) x 10/20 + 2.67
= 2.885 feet per 100 feet

Pressure loss = 2.885 feet x 0.433 psi/foot
=1.25 psi/100feet

TABLE NJ 6.11

Friction Loss in Feet per 100 Feet in Portable Aluminum Pipe with Couplings
(Based on Scobey's Formula with K = 0.32 and 30 foot lengths) [1]

Q	3 in [2] (2.914”)	4 in [2] (3.906")	5 in [2] (4.896")	6 in [2] (5.884")	7 in [2] (6.872")	8 in [2] (7.856")	10 in [2] (9.918")
40	0.528	0.126					
50	0.806	0.192					
60	1.140	0.271					
70	1.528	0.364					
80	1.970	0.469	0.155				
90	2.464	0.586	0.194				
100	3.010	0.716	0.237				
120	4.256	1.013	0.335				
140	5.704	1.357	0.449	0.182			
160	7.351	1.749	0.578	0.235			
150	9.194	2.188	0.723	0.294			
200	11.23	2.673	0.884	0.359			
220	13.46	3.203	1.059	0.430	0.201		
240	15.88	3.779	1.249	0.508	0.237		
260	18.49	4.400	1.455	0.591	0.276		
280	21.29	5.065	1.674	0.680	0.318		
300	24.27	5.775	1.909	0.776	0.363	0.188	
320		6.528	2.158	0.877	0.410	0.213	
340		7.325	2.422	0.984	0.460	0.239	
360		8.166	2.699	1.097	0.513	0.266	
380		9.049	2.991	1.215	0.568	0.295	
400		9.975	3.298	1.340	0.626	0.325	0.109
420		10.94	3.618	1.470	0.687	0.357	0.120
440		11.96	3.952	1.606	0.751	0.390	0.131
460		13.01	4.301	1.747	0.817	0.424	0.142
480		14.11	4.663	1.894	0.885	0.460	0.154
500		15.24	5.039	2.047	0.957	0.497	0.167
550		18.27	6.039	2.454	1.147	0.595	0.200
600		21.55	7.125	2.895	1.353	0.702	0.236
650		25.09	8.295	3.370	1.575	0.818	0.274
700		28.89	9.549	3.880	1.813	0.941	0.316
750		32.93	10.89	4.423	2.067	1.073	0.360
800		37.23	12.31	5.000	2.337	1.213	0.407
850			13.81	5.511	2.622	1.361	0.457
900			15.39	6.254	2.923	1.517	0.509
950			17.06	6.931	3.239	1.681	0.564
1000			18.81	7.640	3.571	1.854	0.622
1050			20.63	8.382	3.918	2.034	0.682
1100			22.54	9.157	4.280	2.222	0.745
1150			24.53	9.964	4.657	2.417	0.811

1 For 20-foot lengths, <u>increase</u> table values by 7 percent
For 40-foot lengths, <u>decrease</u> table values by 3 percent
2 Outside diameter

TABLE NJ 6.11 (Continued)

Friction Loss in Feet per 100 Feet in Portable Aluminum Pipe with Couplings
(Based an Scobey's Formula with K = 0.32 and 30 foot lengths) [1]

Q	3 in [2] (2.914")	4 in [2] (3.906")	5 in [2] (4.896")	6 in [2] (5.884")	7 in [2] (6.872")	8 in [2] (7.856")	10 in [2] (9.918")
1200			26.59	10.80	5.049	2.621	0.879
1250			28.74	11.68	5.457	2.832	0.950
1300				12.58	5.879	3.051	1.023
1400				14.48	6.768	3.513	1.178
1500				16.51	7.716	4.005	1.343
1600				18.66	8.722	4.527	1.519
1700				20.94	9.787	5.080	1.704
1800				23.34	10.91	5.663	1.899
1900				25.87	12.09	6.276	2.105
2000				28.51	13.33	6.918	2.320
2100					14.62	7.590	2.546
2200					15.97	8.291	2.781
2300					17.38	9.022	3.026
2400					18.85	9.782	3.231
2500					20.37	10.57	3.346
2600					21.94	11.39	3.820
2700					23.57	12.24	4.104
2800					25.26	13.11	4.397
2900					27.00	14.01	4.701
3000					28.80	14.95	5.013
3100						15.91	5.336
3200						16.90	5.667
3300						17.91	6.009
3400						18.96	6.359
3500						20.03	6.719
3600						21.13	7.089
3700						22.26	7.468
3800						23.42	7.856
3900						24.61	8.253
4000						25.82	8.660
4100							9.076
4200							9.501
4300							9.935
4400							10.38
4500							10.83
4600							11.29
4700							11.76
4800							12.24
4900							12.73
5000							13.23

1 For 20-foot lengths, <u>increase</u> table values by 7 percent
For 40-foot lengths, <u>decrease</u> table values by 3 percent
2 Outside diameter

TABLE NJ 6.11 (Continued)

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES MANUFACTURED OF PVC OR ABS COMPOUNDS STANDARD DIMENSION RATIO -SDR = 21 [1]

For IPS Pipe

Friction Head Loss in Feet per Hundred Feet

Q Gallons per min	1-inch 1.189 ID	1 1/4-inch 1.502 ID	1 1/2-inch 1.720 ID	2-inch 2.149 ID	2 1/2-inch 2.601 ID	3-inch 3.166 ID	3 1/2-inch 3.620 ID	Q Gallons per min
2	.15	.04	.02					2
4	.54	.17	.09	.03	.01			4
6	1.15	.37	.19	.06	.02			6
8	1.97	.63	.32	11	.04	.01		8
10	2.98	.95	.49	.16	.06	.02	.01	10
15	6.32	2.03	1.04	.35	.14	.05	.02	15
20	10.79	3.46	1.78	.60	.23	.09	.04	20
25	16.30	5.22	2.70	.91	.36	.13	.07	25
30	22.86	7.32	3.78	1.27	.50	.19	.10	30
35		9.75	5.03	1.70	.67	.25	.13	35
40		12.46	6.46	2.18	.86	.32	.17	40
45		15.51	8.02	2.71	1.07	.40	.21	45
50		18.87	9.75	3.30	1.30	.49	.25	50
55		22.48	11.64	3.94	1.54	.59	.30	55
60			13.64	4.62	1.81	.69	.36	60
65			15.85	5.36	2.10	.80	.41	65
70			18.19	6.14	2.42	.92	.47	70
75			20.65	6.99	2.75	1.06	.55	75
80			23.28	7.86	3.10	1.19	.62	80
85				8.81	3.47	1.33	.69	85
90				9.79	3.85	1.48	.77	90
95				10.82	4.25	1.64	.85	95
100				11.89	4.69	1.80	.93	100
110				14.21	5.59	2.14	1.11	110
120				16.69	6.56	2.52	1.31	120
130				19.35	7.63	2.92	1.53	130
140				22.21	8.73	3.36	1.75	140
150					9.94	3.82	1.99	150
160					11.20	4.29	2.24	160
170					12.51	4.80	2.50	170
180					13-90	5.35	2.79	180
190					15.39	5.92	3.08	190
200					16.91	6.50	3.38	200
220					20.19	7.77	4.04	220
240					23.73	9.12	4.76	240
260						10.57	5.51	260
280						12.11	6.32	280
300						13.78	7.18	300
320						15.52	8.10	320
340						17.37	9.07	340
360						19.27	10.08	360
380						21.33	11.13	380
400						23.45	12.22	400
420							13.40	420
440							14.59	440
460							15.86	460
480							17.15	480
500							18.50	500

Table based on Hazen-Williams equation - C = 150

1 To find friction head loss in PVC or ABS pipe having a standard dimension ratio other than 21, the values in the table should be multiplied by the appropriate conversion factor shown below:

SDR No	Conversion Factor
13.5	1.35
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

<u>TABLE NJ 6.11</u> (Continued)

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES MANUFACTURED OF PVC OR ABS COMPOUNDS STANDARD DIMENSION RATIO -SDR = 21[1]

For IPS Pipe

Table based on Hazen-Williams equation C = 150

SDR NO.	Conversion Factor
13.5	1.35
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

Friction Head Loss in Feet per Hundred Feet

Q Gallons per min.	4-inch 4.072 ID	5-inch 5.033 ID	6-inch 5.993 ID	8-inch 7.805 ID	10-inch 9.728 ID	12-inch 11.538 ID	Q Gallons per min
15	.01						15
20	.02						20
25	.04	.01					25
30	.05	.02					30
35	.07	.02	.01				35
40	.09	.03	.01				40
45	.12	.04	.01				45
50	.14	.05	.02				50
55	.17	.06	.02				55
60	.20	.07	.03				60
65	.23	.08	.03	.01			65
70	.27	.09	.04	.01			70
75	.31	.11	.04	.01			75
80	.35	.12	.05	.01			80
85	.39	.14	.05	.01			85
90	.43	.15	.06	.01			90
95	.48	.17	.07	.02			95
100	.52	.19	.07	.02			100
110	.63	.22	.09	.02			110
120	.74	.26	.10	.03	.01		120
130	.85	.30	.12	.03	.01		130
140	.98	.35	.14	.04	.01		140
150	1.11	.40	.16	.05	.01		150
160	1.26	.44	.19	.05	.01		160
170	1.41	.49	.21	.06	.02		170
180	1.57	.55	.24	.07	.02	.01	180
190	1.73	.61	.26	.07	.02	.01	190
200	1.90	.67	.29	.03	.02	.01	200
220	2.28	.81	.34	.09	.03	.01	220
240	2.67	.95	.40	.10	.03	.01	240
260	3.10	1.10	.46	.12	.04	.02	260
280	3.56	1.26	.54	.14	.05	.02	280
300	4.04	1.43	.61	.17	.05	.02	300
320	4.56	1.62	.69	.19	.06	.03	320
340	5.10	1.82	.77	.21	.07	.03	340
360	5.67	2.02	.86	.24	.08	.03	360
380	6.26	2.22	.95	.26	.09	.04	380
400	6.90	2.45	1.04	.28	.10	.04	400
420	7.55	2.69	1.14	.31	.10	.05	420
440	8.23	2.92	1.25	.34	.11	.05	440
460	8.94	3.18	1.35	.37	.12	.06	460
480	9.67	3.44	1.46	.41	.14	.05	480
500	10.42	3.70	1.58	.43	.15	.06	500
550	12.44	4.42	1.89	.52	.18	.07	550
600	14.61	5.21	2.22	.61	.21	.09	600

TABLE NJ 6.11(Continued)
FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES MANUFACTURED OF PVC OR ABS COMPOUNDS STANDAND DIMENSION RATIO - SDR = 21[1]

For IPS Pipe

Q Gallons per min.	4-inch 4.072 ID	5-inch 5.031 ID	6-inch 5.993 ID	8-inch 7.805 ID	10-inch 9.728 ID	12-inch 11.538 ID	Q Gallons per min.
			Friction Read Loss in Feet per Hundred Feet				
600	14.61	5.21	2.22	.61	.21	.09	600
650	16.94	6.04	2.58	.71	.24	.10	650
700	19.45	6.92	2.96	.81	.28	.12	700
750	22.08	7.87	3.36	.93	.32	.14	750
800		8.88	3.78	1.04	.36	.16	800
850		9.93	4.24	1.17	.40	.17	850
900		11.05	4.71	1.30	.44	.19	900
950		12.18	5.21	1.44	.49	.21	950
1000		13.40	5.73	1.58	.54	.23	1000
1050		14.67	6.27	1.73	.59	.26	1050
1100		16.00	6.83	1.88	.65	.28	1100
1150		17.39	7.41	2.05	.70	.30	1150
1200		18.80	8.02	2.21	.76	.33	1200
1250		20.27	8.66	2.39	.82	.35	1250
1300		21.78	9.32	2.57	.88	.37	1300
1350			9.99	2.76	.95	.40	1350
1400			10.66	2.95	1.01	.43	1400
1450			11.40	3.16	1.08	.47	1450
1500			12.13	3.35	1.15	.50	1500
1600			13.68	3.18	1.30	.56	1600
1700			15.29	4.23	1.45	.62	1700
1800			16.99	4.70	1.62	.70	1800
1900			18.81	5.20	1.79	.77	1900
2000			20.66	5.72	1.97	.84	2000
2100			22.61	6.26	2.15	.93	2100
2200			24.67	6.83	2.34	1.01	2200
2300				7.42	2.55	1.10	2300
2400				8.02	2.76	1.19	2400
2500				8.67	2.97	1.29	2500
2600				9.31	3.20	1.39	2600
2700				9.98	3.43	1.49	2700
2800				10.67	3.67	1.59	2800
2900				11.39	3.92	1.69	2900
3000				12.10	4.17	1.81	3000
3100				12.89	4.43	1.92	3100
3200				13.66	4.71	2.04	3200
3300				14.46	4.97	2.15	3300
3400				15.29	5.27	2.28	3400
3500				16.11	5.56	2.41	3500
3600				16.99	5.85	2.53	3600
3700				17.89	6.17	2.67	3700
3800				18.76	6.47	2.80	3800
3900				19.69	6.79	2.94	3900
4000				20.67	7.11	3.08	4000

SDR No.	Conversion Factor
13.5	1.35
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

Table based on Hazen-Williams equation – C1 = 150.

TABLE NJ 6.11 (Continued)

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES MANUFACTURED OF PVC OR ABS COMPOUNDS STANDARD DIMENSION RATIO - SDR - 21 [1]

For PIP Pipe

Friction Head Loss in Feet per Hundred Feet

Table based on Hazen-Williams equation – C = 150.

Q Gallons per min.	4-inch 3.736 ID	6-inch 5.556 ID	8-inch 7.382 ID	10-inch 9.228 ID	12-inch 11.074 ID	Q Gallons per min.
15	.02					15
20	.04					20
25	.06					25
30	.09	.01				30
35	.12	.02				35
40	.15	.02				40
45	.18	.03				45
50	.22	.03				50
55	.27	.04				55
60	.31	.05				60
65	.36	.05	.01			65
70	.42	.06	.02			70
75	.47	.07	.02			75
80	.53	.08	.02			80
85	.60	.09	.02			85
90	.66	.10	.02			90
95	.73	.11	.03			95
100	.80	.12	.03			100
110	.96	.14	.03			110
120	1.13	.16	.04	.01		120
130	1.31	.19	.05	.02		130
140	1.50	.22	.05	.02		140
150	1.70	.25	.06	.02		150
160	1.92	.28	.07	.02		160
170	2.15	.31	.08	.03		170
180	2.39	.35	.09	.03		180
190	2.64	.38	.10	.03		190
200	2.90	.42	.11	.04	.01	200
220	3.46	.50	.13	.04	.02	220
240	4.07	.59	.15	.05	.02	240
260	4.72	.68	.17	.06	.02	260
280	5.41	.78	.20	.07	.03	280
300	6.15	.89	.22	.08	.03	300
320	6.93	1.00	.25	.08	.03	320
340	7.76	1.12	.28	.09	.04	340
360	8.62	1.25	.31	.11	.04	360
380	9.53	1.38	.35	.12	.05	380
400	10.48	1.52	.38	.13	.05	400
420	11.47	1.66	.42	.14	.06	420
440	12.50	1.81	.45	.15	.06	440
460	13.58	1.96	.49	.17	.07	460
480	14.69	2.13	.53	.18	.07	480
500	15.84	2.29	.57	.19	.08	500
550	18.90	2.74	.69	.23	.10	550
600	22.21	3.21	.81	.27	.11	600

1 To find friction head loss in PVC or ABS pipe having a standard dimension ratio other than 21, the values in the table should be multiplied by the appropriate conversion factor shown below:

SDR No.	Conversion Factor
13.5	1.34
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

TABLE NJ 6.11(Continued)
FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES MANUFACTURED OF PVC OR ABS COMPOUNDS STANDARD DIMENSION RATIO - SDR - 21 [1]
For PIP Pipe

Q Gallons per min.	4-inch 3.736 ID	6-inch 5.556 ID	8-inch 7.382 ID	10-inch 9.228 ID	12-inch 11.074 ID	Q Gallons per min.
	Friction Head Loss in Feet per Hundred Feet					
650		3.73	.93	.31	.13	650
700		4.28	1.07	.36	.15	700
750		4.26	1.22	.41	.17	750
800		5.47	1.37	.46	.19	800
850		6.13	1.53	.52	.21	850
900		6.81	1.71	.58	.24	900
950		7.53	1.89	.64	.26	950
1000		8.28	2.07	.70	.29	1000
1050		9.06	2.27	.77	.31	1050
1100		9.87	2.47	.83	.34	1100
1150		10.7	2.69	.91	.37	1150
1200		11.60	2.91	.98	.40	1200
1250		12.51	3.13	1.06	.43	1250
1300		13.45	3.27	1.14	.47	1300
1350		14.43	3.61	1.22	.50	1350
1400		15.43	3.87	1.30	.54	1400
1450		16.47	4.13	1.39	.57	1450
1500		17.54	4.39	1.48	.61	1500
1600		19.76	4.95	1.67	.69	1600
1700		21.11	5.54	1.87	.77	1700
1800		24.58	6.16	2.08	.85	1800
1900			6.81	2.29	.94	1900
2000			7.49	2.52	1.04	2000
2100			8.19	2.76	1.14	2100
2200			8.93	3.01	1.24	2200
2300	Table based on Hazen-Williams		9.70	3.27	1.35	2300
2400	Equation – C = 150		10.49	3.54	1.46	2400
2500			11.32	3.82	1.57	2500
2600		Conversion	12.17	4.10	1.69	2600
2700	SDR No.	Factor	13.05	4.50	1.81	2700
2800	13.5	1.34	13.96	4.71	1.94	2800
2900	17	1.13	14.90	5.02	2.07	2900
3000	21	1.00	15.86	5.35	2.20	3000
3100	26	.91	16.85	5.68	2.34	3100
3200	32.5	.84	17.88	6.03	2.48	3200
3300	41	.785	18.92	6.38	2.62	3300
3400	51	.75	20.00	6.74	2.77	3400
3500			21.10	7.11	2.93	3500
3600			22.23	7.50	3.08	3600
3700			22.39	7.89	3.24	3700
3800			24.37	8.28	3.41	3800
3900				8.69	3.58	3900
4000				9.11	3.75	4000

TABLE NJ 6.11 (Continued)

Footnotes:

ABS - Acrylonitrile - butadiene - styrene

IPS - Iron Pipe Size

PIP - Plastic Irrigation Pipe - has a slightly smaller outside diameter than iron pipe.

PVC - Polyvinyl Chloride

SDR- Standard thermoplastic pipe dimension ratio (determined by dividing the average outside diameter of the pipe in inches by the minimum wall thickness in inches).

Hazen-Williams Formula:

$$Q = 1.318\, C_1 (R_h)^{0.63} S^{0.54} A$$

Where Q = pipe flow, in cubic feet per second
C1 = roughness coefficient
R_h = pipe hydraulic radius (R_h = D/4 for round pipe), in feet
S = slope of total head line (head loss per 100 feet)
A = pipe cross-sectional area, in square feet

Scobey's Formula:

$$H_f = \frac{K_s L Q^{1.9}}{145{,}000{,}000 \times D^{4.9}}$$

Where H_f = Total friction loss in lines, in feet
K_s = Scobey's coefficient of retardation
L = Length of pipe, in feet
Q = Total discharge, in gpm
D = Inside diameter of pipe, in feet

If the sprinkler line is made of only one pipe size, friction losses for the line can be computed as though the pipe carried the entering (maximum) capacity throughout its length and then applying a correction factor based on the number of outlets along the line. Correction factors for multiple outlets are shown in Table NJ 6.12.

TABLE NJ 6.12 CORRECTION FACTOR FOR MULTIPLE OUTLETS [1/]

Outlets (Number)	Value of F_n	Outlets (Number)	Value of F_n
1	1.000	16	0.377
2	.634	17	.375
3	.528	18	.373
4	.480	19	.372
5	.451	20	.370
6	.433	21	.369
7	.419	22	.368
8	.410	23	.367
9	.402	24	.366
10	.396	25	.365
11	.392	26	.364
12	.388	27	.364
13	.384	28	.363
14	.381	29	.363
15	.379	30	.362

1/ Values assume equal sprinkler spacing and flows.

For laterals laid on level ground, the allowable pressure loss due to friction is equal to 20 percent of the average design operating pressure of the sprinklers (Pa). To determine the pipe size, divide 20 percent of Pa by the length of the lateral line in 100-foot segments multiplied by the appropriate Fn factor.

$$\text{Allowable loss per 100 feet (Pf)} = \frac{0.20\, P_a \times 2.31}{L/100 \times F_n}$$

This calculation is based on 30-foot sections. If 20-foot sections are used, divide the result by 1.07; if 40-foot sections are used, divide by 0.97.

Example: Using the previous example and Table NJ 6.12, the allowed pressure loss due to friction would be:

$$P_f = \frac{(0.20)(70) \times 2.31}{600/100 \times 0.396} = 13.61$$

feet of head per 100 feet of lateral with 30-foot sections.

$P_f = 13.61/1.07$
$= 12.72$ feet per 100 feet with 20-foot sections.

Enter Table NJ 6.11 at the 250 gpm line to find the pipe size which corresponds to the allowable loss.

Data in Table NJ 6.11 shows that either 4-inch aluminum or 3 inch PVC pipe could be used.

For laterals laid uphill or downhill, the elevation difference must be considered. The same equation is used as for level lines, but the equation is changed to (0.20 Pa - Pe) x 2.31, where Pe is pressure difference due to elevation increase, in psi. To determine the pressure requirements at the main line (Pm), the pressure required to lift the water through the riser pipe (Pr) must be added in the summary.

For level lines:

- Pm = Pa + 3/4 Pf + Pr

For uphill lines,

- Pm = Pa + 3/4 (Pf + Pe) + Pr

For downhill lines,

- Pm = Pa + 3/4 (Pf – Pe) + Pr

The factor (3/4) is used to provide for the average operating pressure (Pa) at the center of the line rather than at the distal end.

System Capacity

The required rate of flow depends on the size of the irrigated area, the crop moisture needs during peak use, irrigation system efficiency, and time to complete the irrigation cycle.

The rate of flow can be calculated by:

$$Q = \frac{453\ AD}{FH}$$

Where: Q = required flow in gallons per minute (gpm)
A = irrigated area in acres
D = gross depth of application in inches
F = days allowed to complete one irrigation
H = actual operating hours per day

Figure NJ 6.3 is a nomograph for solving this equation.

Example: The size of the system may be reduced by increasing the operating hours per day. For example, a grower wants to apply 2.8 inches of water on a 50-acre field in 6 days by irrigating 12 hours a day. The capacity required would be:

$$Q = \frac{453 \times 50 \times 2.8}{6 \times 12} = 881 \text{ gpm}$$

By extending the hours of operation to 18 hours per day, the required capacity would be:

$$Q = \frac{453 \times 50 \times 2.8}{6 \times 18} = 587 \text{ gpm}$$

Allowable Time To Complete An Irrigation

The allowable time (days) to complete one irrigation cycle is shown in Table NJ 2.1, Column (4) for the effective root zone depths (depth to be irrigated). Where the design area has several soils and crops, the time allowed (days) to apply irrigation is dependent upon a weighted value determined from acreages and allowed days. Several combinations of crops, acreages, and soils need to be evaluated. The system capacity should be based on the combination which has maximum requirements.

Determining The Weighted Gross Water Application

The weighted gross application and weighted days for each crop and acreage combination are used to determine the system capacity. See example that follows.

USING THE IRRIGATION GUIDE FOR A SPRINKLER SYSTEM

Example:

Field No. I	Field No. 2	Field No. 3	Field No. 4
5 Ac Downer loamy sand	10 Ac Sassafras sandy loam	20 Ac Woodstown sandy loam	15 Ac Fallsington sandy loam

Crops: In this example, two cropping cases will be evaluated. In practice, all expected cropping cases should be evaluated to determine maximum requirements.

Field No.	Case 1	Case 2
1	Potatoes	Soybeans
2	Carrots	Sweet Corn
3	Sweet Corn	Carrots
4	Snap beans	Potatoes

Operation Conditions

Management-allowed depletion of available moisture is 50 percent
System efficiency for design is 70 percent
System to be operated 16 hours per day
Design consumptive use rate is 0.2 inches per day.

Case 1:

Field No.	Soil Series	Crop	Effective Root Zone Depth for Irrigation (inches)1/	Available Moisture Capacity (inches)2/	Gross Water Application (inches)3/	Allowable Days4/	Acres in Field	Gross Application (Acre-Inches)	Acre-Days
1	Downer	Potatoes	18	2.3	1.6	6	5	8.0	30
2	Sassafras	Carrots	12	1.6	1.1	4	10	11.0	40
3	Woodstown	Sweet Corn	24	3.7	2.6	9	20	52.0	180
4	Fallsington	Snapbeans	18	3.3	2.4	8	15	36.0	120
						Totals	50	107.0	370

1/ Table NJ 3.3
2/ Table NJ 2.1, Column 3
3/ Available Moisture Capacity x Management Allowed Depletion (decimal fraction) / System Efficiency (decimal fraction).
4/ Table NJ 2.1, Column 4

$$\text{Weighted gross water application} = \frac{107.0\ \text{acre-inches}}{50\ \text{acres}} = 2.1\ \text{inches}$$

$$\text{Weighted days to complete irrigation} = \frac{370\ \text{acre-days}}{50\ \text{acres}} = 7.4\ \text{days}$$

The system capacity for this combination is:

$$Q = \frac{453\ AD}{FH} = \frac{(453)\ (50)\ (2.1)}{(7.4)\ (16)} = 402\ \text{gpm}$$

Case 2:

Field No.	Soil Series	Crop	Effective Root Zone Depth for Irrigation (inches)	Available Moisture Capacity (inches)	Gross Water Application (inches)	Allowable Days	Acres in Field	Gross Application (Acre-Inches)	Acre-Days
1	Downer	Soybeans	24	3.1	2.2	8	5	11.0	40
2	Sassafras	Sweet Corn	24	3.6	2.6	9	10	26.0	90
3	Woodstown	Carrots	12	1.8	1.3	4	20	26.0	80
4	Fallsington	Potatoes	18	3.3	2.4	8	15	36.0	120
						Totals	50	99.0	330

$$\text{Weighted gross water application} \quad \frac{99.0\ \text{acre-inches}}{50\ \text{acres}} = 2.0\ \text{inches}$$

$$\text{Weighted days to complete irrigation} = \frac{330\ \text{acre-days}}{50\ \text{acres}} = 6.6\ \text{days}$$

The system capacity for this combination is:

$$Q = \frac{453\ AD}{FH} = \frac{(453)\ (50)\ (2.0)}{(6.6)\ (16)} = 429\ \text{gpm}$$

In practice, time should be allowed for emergencies such as breakdown of equipment. While the computed minimum system capacity is 429 gprn, the operational plan may call for a maximum of 6 days operational time to satisfy the crop water requirement. The system capacity would then be:

$$Q = \frac{(453)\ (50)\ (2.0)}{(6)\ (16)} = 472\ \text{gpm}$$

Design of the Main Line

Pressure losses due to friction are the principal consideration in the design of any pipe system. The basic problems vary according to the source of pressure.

Where pressure is applied by pumping as in a sprinkler irrigation system, the problem is one of selecting main line pipe sizes and materials that will result in a reasonable balance between pumping costs and the capitalized costs of the pipe. Obtaining a satisfactory design that results in the lowest annual application cost is the ultimate objective.

The design of complex sprinkler irrigation systems such as split-line layouts, multiple laterals, and graduated line sizes is discussed in Chapter 11, Sprinkler Irrigation, National Engineering Handbook, Section 15.

Main line design for a single lateral operation entails selection of a pipe which will carry the rate of flow required at an acceptable loss in pressure head.

Example: A 1000-foot aluminum main line is required to carry 280 gpm. Allowable head loss is 35 feet. The main line rises 3 feet between the pump and the distal end. What pipe size is needed?

H_f = 35.0 - 3.0 = 32.0 feet (allowable friction loss in main)

$$H_f = \frac{32.0}{1000/100} = 3.20 \text{ feet per 100 feet}$$

Table NJ 6.11 shows that a 5-inch line would be required.

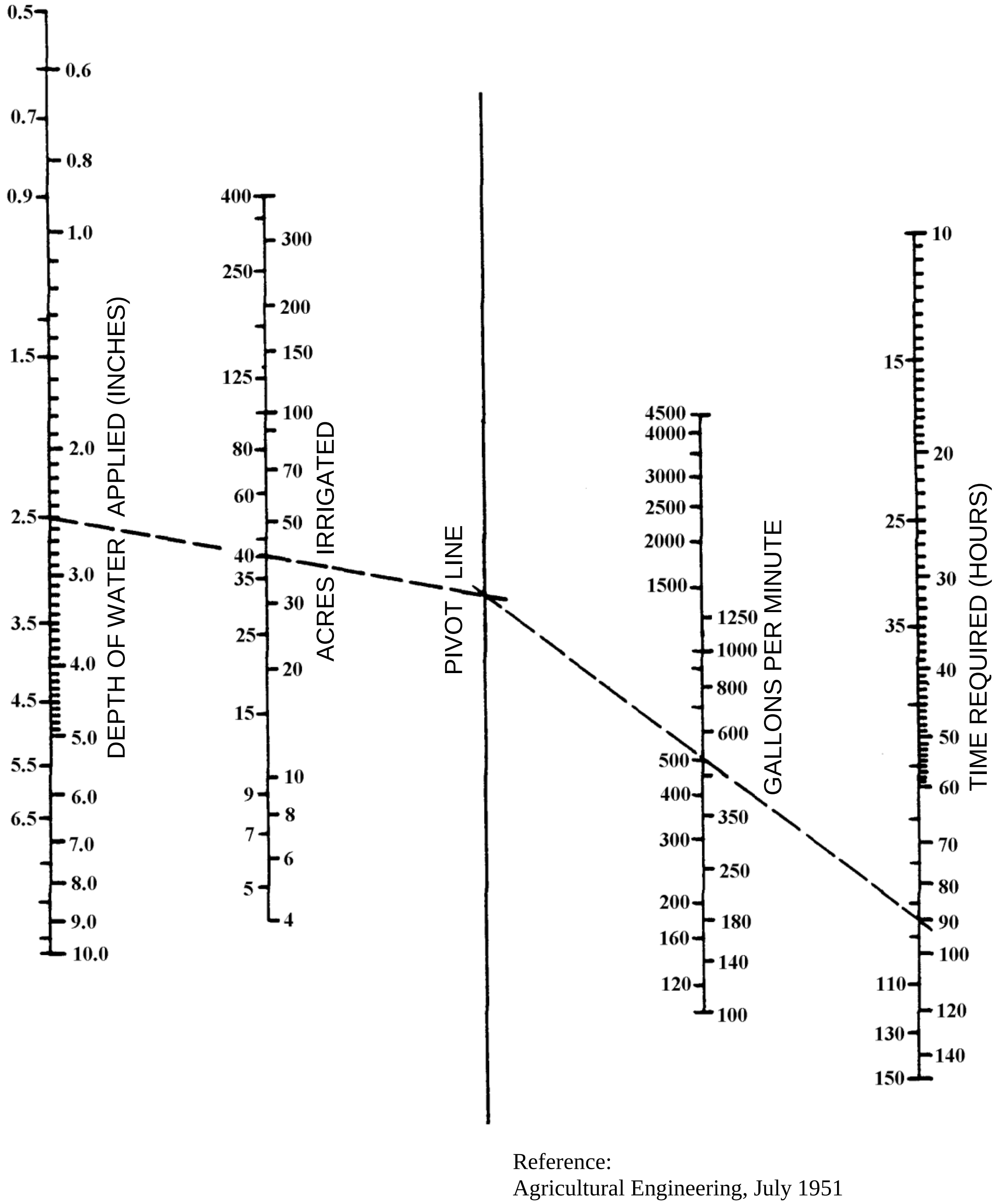
Actual loss would be:

H_f = (1000/100 x 1.674) + 3.0 = 19.74 feet

Sprinkler Irrigation System Design Procedure for Cranberries:

Frost Control: The following step-by-step procedure is normally used in planning a sprinkler irrigation system for frost control on cranberries. For other crops, application rates, or sprinkler types, refer to NJIG Chapters 4 and 6.

1. Lay out and number the laterals (letters).
2. Determine size of the lateral pipes using Table NJ 6.13 (for 40 psi., 40' x 50' spacing, 5/32" nozzle, 4.45 gpm; or for 55 psi, 52' x 63' spacing, 5/32" nozzle, 5.7 gpm).
3. Set up tabulation sheet for head losses on main.
4. Determine sizes and lengths of the main, using pipe capacities chart, Table NJ 6.14 (As a guide, use maximum 6 psi loss on main).
5. Compute friction loss on main. (Use Table NJ 6.11)
6. Compute pump capacity (NJIG Chapter 7).
7. Compute main line quantities.
8. Compute lateral line quantities.
9. Determine thrustblock sizes.
10. Complete the plan view.



Reference:
Agricultural Engineering, July 1951

<u>Figure NJ 6.3 Capacity Requirements for Irrigation Systems</u>

TABLE NJ 6.13a, DESIGN OF LATERALS FOR CRANBERRY BOG FROST CONTROL

DATA: 40’ Sprinkler Spacing x 50’ Lateral Spacing; Design Application Rate = 0.22”/hr; 5/32" Nozzle - 40 psi ; 4.45 gpm; wetted diameter = 88’; C = 140; V = 5.0 fps (Max.); Controlled ID PE PIPE; Max. Pressure Loss = 8.0 psi/Lateral.

LATERAL LAYOUT

		Main to First Sprinkler		First to Last Sprinkler	
Number of Sprinklers per Lateral	Total Flow GPM	Max Distance Feet	Pipe Diameter Inches	Pipe Lengths Feet	Pipe Diameters Inches
1	4.45	5000	1 1/4”		
2	8.90	1376	1 1/4”	40	1 1/4”
3	13.35	631	1 1/4”	80	1 1/4”
		1336	1 1/2”	80	1 1/4”
4	17.80	347	1 1/4”	120	1 1/4”
		735	1 1/2"	120	1 1/4”
5	22.25	203	1 1/4”	160	1 1/4”
		460	1 1/2”	40	1 1/2”
				120	1 1/4”
6	26.70	246	11/2”	200	1 1/4”
		833	2”	200	1 1/4”
7	31.15	155	1 1/2”	40	1 1/2”
				200	1 1/4”
		525	2”	40	1 1/2”
				200	1 1/4”
8	35.60	304	2”	80	1 1/2”
				200	1 1/4”
		498	2”	80	2”
				40	1 1/2”
				160	1 1/4”
9	40.05	212	2”	40	2”
				80	1 1/2”
				200	1 1/4”
		453	2”	200	2”
				80	1 1/2”
				80	1 1/4”
10	44.50	175	2”	800	2”
				80	1 1/2”
				200	1 1/4”
11	48.95	113	2”	120	2”
				80	1 1/2”
				200	1 1/4”

TABLE NJ 6.13b, DESIGN OF LATERALS FOR CRANBERRY FROST CONTROL

DATA: 52’ Sprinkler Spacing x 63’ Lateral Spacing; Design Application Rate = 0.17”/hr; 5/32" Nozzle - 55 psi –5.7 gpm; wetted diameter = 105”; C = 140; V = 5.0 fps (.Max.); Controlled ID PE PIPE; Max. Pressure Loss = 11.0 psi/Lateral.

LATERAL LAYOUT

		Main to First Sprinkler		First to Last Sprinkler	
Number of Sprinklers per Lateral	Total Flow GPM	Max Distance Feet	Pipe Diameter Inches	Pipe Lengths Feet	Pipe Diameters Inches
1	5.7	4349	1 1/4”		
2	11.4	1192	1 1/4“	520	1 1/4”
3	17.1	538	1 1/4“	104	1 1/4“
4	22.8	285	1 1/4”	156	1 1/4”
		605	1 1/2”	156	1 1/4”
5	28.5	327	1 1/2”	208	1 1/4”
		1100	2”	208	1 1/4”
6	34.2	664	2”	52	1 1/2”
				208	1 1/4”
7	39.9	460	2”	52	2”
				52	1 1/2”
				208	1 1/4”
		596	2”	104	2”
				52	1 1/2”
				156	1 1/4“
8	45.6	319	2”	52	2”
				52	1 1/2”
				208	1 1/4”
		526	2”	260	2”
			1 1/2”	52	1 1/2”
			1 1/4”	52	1 1/4”
9	51.3	214	2”	156	2”
				52	1 1/2”
				208	1 1/4”

TABLE NJ 6.14 PVC PIPE CAPACITIES, 160 PSI, PR, SDR 26 MAXIMUM VELOCITY 5.0 FT/SEC

PIPE DIA	MAX. GPM	MAXIMUM NO. OF SPRINKLERS @ 4.45 GPM
3”	126.1	28
4”	209.1	47
6”	453.1	101
8”	768.0	172
10”	1193	268
12"	1679	377

d) Microirrigation Systems

Microirrigation consists of frequent low volume, low pressure application of water on or beneath the soil surface. Emission devices used in New Jersey consist of drip emitters that are either in-line (integrated inside the tube or tape) or on-line drippers (external on drip tube), and mico 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 is called an emitter. Water moves through the soil form the emission point to soil areas of higher water tension by both capillary and gravity forces. The amount of soil wetted depends on soil characteristics, length of irrigation period, emitter discharge, and number and spacing of emitters. 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 – 90 percent. The greatest water management problem is over-irrigation.

Thorough planning is essential to properly design, install, and operate a microirrigation system. Consider the following factors before choosing a specific system.

Types of Microirrigation Systems

There are two categories of emitters based on field application: line-source and point-source.

The line-source emitter system consists of a series of equally spaced emission points along a single or double chamber tube. Tubing can consist of flexible hose, tape, or semirigid tubing that retains its shape. The discharge rate is usually given in gallons per minute (gpm) per unit length. Line-source emitters should be used only on level or gently sloping land. Because the operating pressure is low, usually less than 15 psi, a moderate elevation change will cause a large variation in discharge. The line-source emitter is used for closely spaced row crops, such as vegetables and some small fruit, and in greenhouses for irrigation on a mat.

The point-source emitter is an individual emitter that is usually connected to a plastic pipe. This emitter can be on the outside of the tubing or integrated inside the tubing. Water is applied 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 gallon per hour to nearly 0.5 gallon per minute for individual drip emitters. Point-source systems operate under somewhat higher pressures than line-source systems. 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 small fruits such as blueberries, grapes, and brambles, tree fruit crops, and ornamental trees and shrubs, where plants are widely spaced. It is also used for container-grown nursery or greenhouse crops.

Pressure-compensating emitters have been developed that have nearly the same discharge rate over a wide range of line pressure. The pressure-compensating emitter is useful in hilly terrain where elevation differences can cause significant line pressure variations, and fields with long row lengths.

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 – 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. This type of microirrigation system works well with most tree fruit crops especially on sandy soils. The micro sprinkler system has the advantage of wetting more of the root zone area then single emitters on these soils. 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 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.

Water Requirements

Determine the cost and availability of water first. There must be a sufficient supply of good quality water before any irrigation system can be planned. Evapotranspiration from a vegetable row crop is about 5400 gallons of water per acre per day (0.20 in./day x 27,160 gallons per acre-inch). An orchard may use 50 percent of this amount. The source must supply the required quantity of water at the design application rate. The design application rates could range between 6 gpm and 90 gpm per acre, depending on length of application time and the emitter system.

The system can be designed to operate less frequently than daily, but the application per irrigation would be larger. The delivery system must either be sized for a larger flow rate or be operated longer to apply the necessary water.

Trees and Small Fruits

Water requirements for trees and small fruit crops may be estimated from Tables NJ 6.15 and NJ 6.16. The values take into account that rainwater stored in the soil supplies part of the water needs. This reliance on rainfall contrasts with designs for arid climates where rainfall and soil water holding capacity are considered relatively unimportant under trickle irrigation. The amount applied approximates the average daily evapotranspiration that occurs during summer drought periods lasting 20 to 30 days.

TABLE NJ 6.15_ IRRIGATION WATER REQUIREMENTS (GALLONS/DAY) FOR SMALL FRUIT USING LINE SOURCE OR POINT SOURCE EMITTERS

Crop (Spacing in feet)	Plant Age in Years		
	1-2	3-4	5-20
		Gallons per Day	
Strawberries 1/ (2 x 4)	.25 gal/plant or 10 gal/100 ft	.5 gal/plant or 27gal/100 ft	
Raspberry Blackberry 2/ (2.5'x 10')	.5 gal/ plant or 20 gal/100ft	1 gal / plant or 40 gal/ 100 ft	1.5 gal/ plant or 60 gal/ 100 ft
Blueberry 3/ (3.5 x 9)	.5 gal/ plant or 15 gal/100 ft	2 gal/ plant or 50 gal/100 ft	3.5 gal/ plant or 85 gal/ 100 ft

1/ Crop evapotranspiration rate estimated at 0.11 inch per day for peak month (June, 3 -4 year old plant). Assume E_{to} = .2"/day; K_{c1} = .7; and; K_{c2}, canopy coefficient = .76
2/ Crop evapotranspiration rate estimated at 0.1 inch per day for peak month (July, 5 - 20 year old plants). Assume E_{to} = .2"/day; K_{c1} = 1.05; and; K_{c2}, canopy coefficient = .5
3/ Crop evapotranspiration rate estimated at 0.15 inch per day for peak month (July, 5 - 20 year old plants). Assume E_{to} = .2"/day; K_{c1} = 1.1; and; K_{c2}, canopy coefficient = .7

TABLE NJ 6.16_ IRRIGATION WATER REQUIREMENTS FOR TREE FRUIT, GRAPES, AND BRAMBLES WITH POINT-SOURCE EMITTERS[1/]

Crop (Spacing in feet)	Plant Age in Years					
	1	2	3	4	5	6-20
			Gallons per Day per Plant			
Apple						
(6 x 14 trellis)	1.0	1.25	3.0	4.5	5.0	8.0
(14 x 22)	1.0	3.0	5.0	12	26.0	31.0
(18 x 26)	1.0	3.0	5.0	12	28.0	60.0
Peach, Nectarine, Plum						
Standard (15 x 22)	1.0	2.5	4.5	11	24	38
Grapes, Thornless Blackberry						
(6 x 10)	.5	1.0	1.0	2.0	2.5	3.0

1/ Assume pan evaporation averages 0.2" per day during peak season

Vegetable and Melon

The water required daily per 100 feet of row crop can be determined by the equation:

$$Q = 50 \times E_P \times S$$

Where: Q = gallons required per 100 feet per day
Ep = average daily pan evaporation inches per day, July (use 0.2" per day for average peak month, NJ)
S = row spacing in feet

Average Kc for vegetables is .8 (included in conversion factor 50)

Vegetable crops may be watered daily for one or two hours or three times a week for two to four hours each time. Plan an application rate of about 1/2 gpm per 100 feet of row.

Example: Plant melons on 5 foot row spacing on a two acre square field. The soil texture is coarse. Pan evaporation is estimated to be an average of 0.2 inch/day in July. How much net irrigation application should be applied each day? At 90% system efficiency what is the gross irrigation application?

The quantity of water needed is:

$$Q = 50 \times E_P \times S = 50 \times 0.2 \times 5$$
$$= 50 \text{ gallons per 100 feet per day}$$

$$Q = \frac{50 \text{ gallons per 100 feet per day}}{.9}$$
$$= 55.6 \text{ gallons per 100 feet per day}$$

e) Microirrigation System Design

System Components

System components should include the following starting at the water source: (Refer to Figure NJ 6.4)

1. Prescreening and filtration of debris, organic material or coarse sediments from surface water, such as sand media filter with automatic backflush, or automatic disc filters that backflush with preset pressure differential; or if sand is being pumped from 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 plastic pipe sized for pumping capacity and irrigation water requirements.
6. Submains: typically PVC plastic pipe with control valves, pressure regulators, drains and air vents as necessary.
7. Lateral lines: typically surface or buried PE plastic tubing or tape.
8. Emission devices.
9. Automatic flush valves at ends of laterals
10. Appropriately placed soil moisture sensing devices for irrigation scheduling. Scheduling can be manual or if feasible automated using a controller and electric solenoid valves.

Planning and Design Considerations

Water Supply – Water quality and quantity is usually the most important consideration when determining whether a microirrigation system is physically feasible. Well and surface water can contain high concentrations of undesirable minerals and sand. Surface water can contain organic debris, algae, bacteria, soil particles, and other material. In designing a micro-irrigation 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 preventors to protect water quality if injecting chemicals or fertilizer.

Clogging – Clogging is the most serious problem of micro irrigation. Properly designed and maintained filtration systems generally protect the system from most clogging. Clogging causes poor water distribution and may damage the crop if emitters are plugged for a long time. 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 stopwatch.

Table NJ 6-17 Physical, chemical and biological factors causing plugging of emitters

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

Figure NJ 6.4 Micro systems components

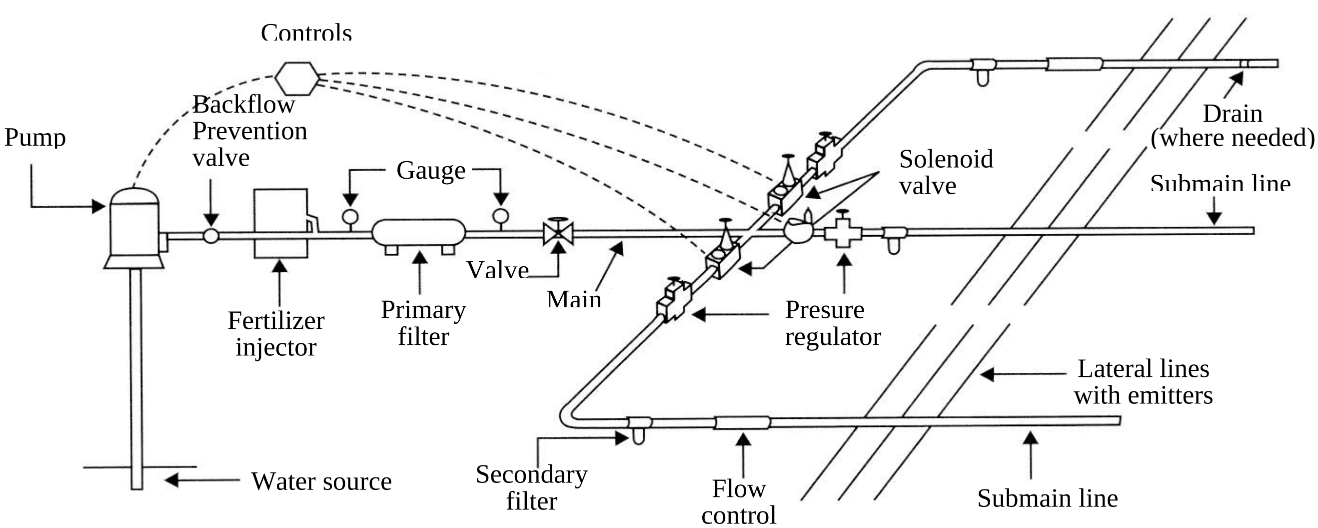


Table NJ 6-18 Plugging potential from irrigation water used in micro irrigation systems

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

1/ Bacteria populations reflected algae and microbial nutrients.

Filter Systems – All water must be screened or filtered to some degree before used in a micro irrigation system. Water quality, temperature, flow rate, and emitter orifice size determine the type of filter. Types of filters commonly used in NJ 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 backflushing disc filters can be used on surface water filtration); and sand separators, (used mostly on wells with fine sand problems).

Soil Wetting Patterns - Soil moisture distribution and the extent of soil wetting should be a major consideration in the design of any micro irrigation system.

The volume of soil wetted depends on the emitter type, discharge rate, distance between emitters, time of set, and soil texture. In general, the diameter of the wetted volume will increase with an increase in clay content, discharge rate, and irrigation run time. The shape of the wetted volume depends on soil capillary forces and gravity. In clay soils, the capillary forces are very strong and gravity forces are relatively unimportant. Flow from the emitters moves horizontally and vertically at almost the same rate to form a bulb-shaped wetted volume. Unlike clay soils, gravity plays an important role in sandy soils. The result is a cylinder-shaped wetted volume. Coarse textured soils, therefore, require more emitters or closer emitter spacing to obtain adequate irrigation for root development.

After an irrigation is stopped, soil water will redistribute until equilibrium is reached. The diameter and area of the soil wetted by an emitter is listed in Table NJ 6.19. Generally, emitters with high flow rates (2 gph) that operate a long time wet more area.

TABLE NJ 6.19 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

Distribution Lines -The micro irrigation distribution system is a network of pipes, tubing, and valves. Generally, mainlines carry water from the pump to a system of submains. Submains then carry the water to headers (manifolds), and then into laterals for feeder lines. Mainlines and submains are generally buried PVC plastic pipe. Fittings are cemented or use O-ring gaskets for water tightness. Submains can also be flexible tubing either buried or laid on the ground surface. Mainlines and submains are typically buried to provide access and limit potential equipment damage. Lateral lines are normally 16mm – 20mm (½” – ¾”), diameter polyethylene (PE) flexible tubing either buried or laid on the ground surface. Lateral fittings generally are slip joint with hose clamps for water tightness.

Control Devices and Management Tools

Gate valves, butterfly or wafer valves, and ball valves: Commonly used to provide on-off control. Gate valves can be operated with timed or automatic solenoid valves.

Pressure regulating, reducing, and sustaining valves: Control pressure within desired limits of emitter discharge.

Vacuum and Air Relief Valves: Air relief valves help prevent pipe water hammer and surge and should be designed 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. This is recommended at the beginning of each drip zone after the control valve. Combination air/vacuum relief valves are generally used on all drip systems.

Flow Meters and Pressure Gauges: These monitor pressure in the system and flow rate (how much water is being pumped to the system). These devices are good management tools for detection of leaks or clogs in the system. The 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.

Flushing Valves: These are recommended to flush sediment or debris from the system. They are often designed at the end of each lateral line and are automatic.

Drain Valves: These are designed at the ends of the manifold to drain water from the system to protect buried pipe from freezing.

Backflow Prevention Devices: 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, pressure vacuum breakers (AVB), double check valves (DC), and reduced pressure vacuum breakers (RP). To protect against contaminants due to backsiphonage and back pressure, only a reduced pressure backflow preventer should be designed (RP).

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 if 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 certain chemicals which may 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, diaphragm, or piston pumps, and internal combustion engines.

Venturi Injectors - This works 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.

Fertigation - The application of plant nutrients through a micro irrigation 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 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 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 agronomic information on the effects of a micro irrigation system on crop yields.

Maintenance - Frequent maintenance is essential to keep emitters functioning at design flow rates. A good operation and maintenance program are 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 backflushing 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.

Automation - Micro irrigation systems can be operated fully automatic, semiautomatic, or manually. A time clock, or programmed control panel can be installed to operate solenoid valves, to start and stop the irrigation, and to control each submain and lateral. This degree of automatic control is simple, the parts are readily available, and it effectively controls the desired amount of water to be applied. A manual priority switch that can override clock or control panel switches is desirable to postpone or add irrigations. A fully automatic system, using soil moisture sensors to provide the triggering mechanism to start and stop an irrigation, can also be designed. This can be applied easily with an electric pump relay system. Several sensors are recommended, depending on soils and rooting depth of crops grown. Over-irrigation can be a management problem with automated systems that do not use soil moisture sensors for starting and shutting down the system.

Design Procedures

The primary objective of good micro irrigation system design and management is to provide sufficient system capacity to adequately meet crop-water needs. Uniform application depends on the uniformity of emitter discharge, system maintenance, and elevations of the ground surface. Nonuniform 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.

Filtration
Design of filtration systems requiring sand media filters shall consider flow rates and filtration during backflushing. Recommended media tank sizes for emitter and row crop drip systems should be based on less then 37 GPM/sqft during backflushing as indicated below.

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

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

Water Management
Proper water management with micro irrigation 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 micro irrigation. The irrigation system designer needs to have realistic expectations of water management skills and desires of the user.

Irrigation Run Time
The duration of each irrigation application is influenced by the overall irrigation schedule (based on available water holding capacity and crop water use), and by incorporating a safety factor in the design. Application time must be sufficient to apply the water that has been consumed since the previous irrigation or rainfall. The duration of each irrigation can be determined after the following are known:

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

Divide the gallons of water per day per plant by the application rate per emitter to calculate the length of time the system must run daily.

Hours of irrigation =

$$\frac{\text{Gallons of water per plant per day}}{\text{Application rate of emitter, gph x number of emitters per plant}}$$

Gallons of water needed per day per plant are calculated using the evapotranspiration rate of the plant, soil MAD level (25% for micro systems), and AWC within the plant root zone. Even if water used by the plant is to be replaced daily, it is recommended a 3-day water supply be stored in the plant root zone to provide water when irrigation system discharge is interrupted. If the system operates less frequently than daily, increase the hours of irrigation proportionally, or the number of emitters per plant to increase water applied each irrigation.

Systems should be designed to run no more then 18 - 22 hours per day, and preferably less. Time is needed for servicing the system, allowance for breakdowns, to permit extra operation during drought periods, and to provide a safety factor during extreme high plant water use periods. Using more emitters of the same discharge rate with less duration is generally better than fewer emitters with greater capacity.

Example: A line source emitter system is designed to apply 68 gallons per 100’ of row per day to a two-acre square field (295' long on a side) with a row spacing of 5 feet. Manufacturer specifications state that the tubing may be run 290 feet on the level. Thus the main line may be placed on one side of the field rather than down the middle. The flowrate is 0.52 gpm per 100 feet of run. Find the irrigation time:

$$\text{Irrigation Time} = \frac{\text{Daily application}}{\text{Emitter application rate}}$$

$$= \frac{68 \text{ gal/ } 100'/\text{day}}{0.52 \text{ gpm}/100'}$$

$$= 131 \text{ min} = 2.2 \text{ hr}$$

There are 295/5 = 59 rows in the field, so the water demand for full operation will be 90.5 gpm (59 x 0.52 x 295/100). A pump that delivers 90.5 gpm through a large 3" main could water the entire field at once. But it is better to divide the field into four zones or subunits because the main lines can be reduced to 1 ¼" or 1 ½" and only a 23 gpm pump would be needed. The total system operating time would then increase to 4 x 2.2 = 8.8 hours per day.

Emitter Discharge Rates

Drip emitters are mechanical devices located either internally within the drip tubing/tape, or externally (on line). They are designed to operate at low pressures (5 – 12 psi for non pressure compensated tape, and 7 – 40 psi for pressure compensated emitters typical on point source or in line emitters), and low flow rates ranging from 0.5 gallon per hour to nearly 0.5 gallon per minute for point source emitters and 0.5 gallons per 100' for line source emitters (tape). Discharge rates of line source emitters are generally in units of gallons per hour per 100' of lateral line.

Emitter Hydraulic Characteristics

Microirrigation emitter flow rates have a different response to pressure variations. The response of a specific emitter depends on its design and construction.

The relationship between the emitter operating pressure and flow rate is given by the following equation:

$$Q = Kd\,(P^x)$$

where,

Q = flow rate (gph),

P = hydraulic head or pressure (psi) at the emitter,

Kd = the emitter discharge coefficient, which is a constant dependent on units,

x = the pressure discharge exponent.

The emitter exponent is a measure of flow rate sensitivity to pressure changes. The value of 'x' is usually between 0 and 1. The larger the 'x' value, the more sensitive the emitter is to pressure variation.

A value of 1.0 means that for each 10% change in pressure, there is a corresponding 10% change in flow rate. A value of 0.5 means that for each 10% change in pressure, there is a corresponding 5% change in flow rate. In contrast, an 'x' value of 0 means that the emitter flow rate does not change as pressure changes. Normally, the 'x' coefficient is about 0.5 for labyrinth-type and orifice control emitters, less than 0.5 for pressure-compensating emitters, and greater than 0.5 for long flow path or spaghetti tube emitters.

Example:

Determine the emitter flow rate if lateral line pressure is 8 psi and the emitter Kd and x values are 0.0954 and 0.5, respectively.

Solution:

$Q = Kd(P^x) = 0.0954(8^{0.5}) = 0.27$ gph.

Number of Emitters

Micro irrigation requires a decision to be made about the percentage of potential rooting volume to be watered. In New Jersey, it is recommended at least 25 - 60 percent of the root zone area for trees, small fruit, or shrubs be wetted. The root zone area can be estimated by the projection of canopy onto the ground. With vegetable and row crops, 100 percent of the root zone area should be wetted. The rate of application should be between the intake rate of the soil and the minimum discharge rate of the applicators. Table NJ 6.20 can be used as an emitter selection guide.

Emitter Location

Line-source emitters are either buried several inches deep or placed beside the plants in a row to wet the root zone. In young orchards, point-source emitters should be close to the young tree to wet within the canopy and root zone area, (however not so close that the trunk is continually wetted, or water pools around the trunk). Ideally, the emitter should be moved farther from the trunk as the tree grows. If using micro jet sprinklers, they should be designed with deflector devices to avoid wetting the tree trunk. Emission devices should be at least 18" from the trunk of the tree to prevent crown rot.

TABLE NJ 6.20 SUGGESTED EMITTERS

Type of Crop	Emitter Recommendations
Dwarf trees	Minimum of one-two 1 gph emitters per plant. Space at least 18" from trunk.
Vine and berries	Normally one - two .5gph - 1gph emitters per plant.
Semi dwarf and standard trees	Two 1 gph emitters per tree. May need 3 or more emitters in sandy soils (depends on canopy area)
Vegetable crops	Use line source emitter.

Example: At maturity, apple trees in a medium textured soil spaced 18'apart in rows 26'wide should receive 60 gallons per day. Several exterior factors may influence the irrigation design but several possibilities include:

a) Use three 1 gph emitters/tree for 20 hours of irrigation
b) Use four 1gph emitters/tree for 15 hours of irrigation.
c) Use six 1 gph emitters/tree for 10 hours of irrigation.
d) Use four 2 gph emitters/tree for 7.5 hours of irrigation.

Assuming the trees touch in the rows, their diameter is 18 feet (mature tree). The minimum wetted area for a mature tree is:

$$A = 25\% \times \frac{\pi D^2}{4} = 64 \text{ square feet}$$

Since the emitters wet 12 to 20 square feet in medium soil, plan to install a minimum of four emitters per tree.

Sizing Laterals

After the emitters are selected and the amount of water to be applied is calculated, the distribution lines must be designed. A guiding principle is to size lines so there is no more than a 10% difference in discharge between the first and last emitter on the line, and 20% within the irrigation zone. The total pressure variation in both the manifold (submain) and laterals must be considered when sizing pipelines. In an optimum design, the total pressure loss within the zone should be equally divided between the manifold and the laterals. For example, if a total of 4 psi pressure variation is allowed, 2 psi can be lost in the manifold and 2 psi in the laterals. Even though pressure compensating emitters may be used, lateral friction loss must be evaluated to help assure minimum pressures are maintained for proper emitter and regulator operation. With non-pressure-compensating emitters, discharge should not vary more than 20% if the pressure difference from the first emitter to the last emitter varies 25% to 30%. For example, the pressure on a typical emitter that discharges 1 gph at 15 psi may vary from 13 to 17 psi and the discharge will only vary 20% or from 0.9 gph to 1.1 gph. With pressure-compensating emitters, pressure may vary from 50% to 100% of the design pressure before flow varies more than 20%. Use Table NJ 6.21 as a guide to allowable line losses.

Block Flow Rate Variation:

$$\text{Flow Rate Variation} = \frac{\text{Maximum Discharge - Minimum Discharge}}{\text{Average Design Emitter Discharge}} \times 100$$

For a well designed system, the greatest emitter discharge minus the smallest emitter discharge divided by the average emitter discharge, multiplied by 100, should be less than 20%.

Submain Sizing

In many cases, laterals may be level or nearly so, but the submain that feeds them is not. Where slopes are 5% or more, submains must often be modified by one of the following techniques to prevent the pressure variation in the subunit from being too great.

TABLE NJ 6.21 RECOMMENDED MAXIMUM PRESSURE RANGES FOR TYPICAL EMITTERS[1/]

	Non-pressure Compensating	Pressure Compensating[2/]
Design pressure	15 psi 20 psi	15 psi 20 psi 30 psi
Pressure range[3/]	13-17 psi 17-23 psi	10 - 20 psi 13 - 28 psi 19 - 41
Pressure variation	4 psi 6 psi	11 psi 15 psi 22psi

1/ Based on 20% flow rate variation.

2/ Pressure compensating emitters are available with allowable maximum pressures up to 50 psi or more.

3/ The allowable pressure range is an estimate for typical point-source emitters and is included to illustrate the advantages of pressure-compensating emitters only. If available, manufacturer's discharge data should be used instead.

1) Divide the submain into shorter lengths so it doesn't have more than about a 10 foot elevation drop between the inlet and the lowest outlet. Then size the submain so total friction loss about equals the elevation pressure gain.

2) Install pressure regulators along the submain to reduce pressure variation due to slope.

3) Install flow control devices between the submain and each lateral. Adjust to equalize flow into each lateral.

4) Connect the laterals to the submain with small diameter tubing. By selecting the proper length and diameter, the flow to each lateral can be regulated. Different length tubes must be installed for each lateral.

5) Use pressure-compensating emitters. Pressure-compensating emitters are commonly used on hilly sites.

Designing Laterals And Submains

Design Formulas:

Friction loss in a lateral or up to 1 ½” manifolds can be calculated by the formula

$P = 0.0006\, Q^{1.75}\, D^{-4.75}\, (L + N\, Le)\, Fe$

where: P = pressure drop in the pipe in pounds per square inch (psi).
Q = total flow rate in gallons per minute (gpm) or the number of outlets or emitters multiplied by the average flow rate per outlet.
D = pipe inside diameter in inches (Table NJ6.22).
L = total pipe length in feet.
Le = an emitter equivalent length factor to correct for added resistance from the emitters. Table NJ6.23 lists values for typical emitters.
N = number of outlets or emitters.
Fe = A correction multiplier to account for the discharge through outlets or emitters along the pipe. Table NJ6.24 lists Fe values.

1/ Formula derived from the equation

$p = f\, (L/D) V^2/2g$

where: p = pressure drop in feet

$f = 0.32 / (\text{Reynolds No.})^{0.25}$ for smooth pipe as developed by Blasius.

V = average water velocity in feet per second

g = acceleration of gravity, 32.2 feet per second per second

TABLE NJ 6.22 PLASTIC PIPE DIAMETERS

Polyethylene (any grade)		PVC Pipe 160 psi (SDR 26)	
Nominal Diameter	Inside Diameter, in.	Nominal Diameter	Inside Diameter, in
3/8”	0.375	2”	2.193
15 mm	0.580	2 ½”	2.655
½”	0.622	3”	3.230
16 mm	0.630	4”	4.154
20 mm	0.800	6”	6.115
¾”	0.824		
1”	1.049		
1 ¼”	1.380		
1 ½”	1.610		
2”	2.067		

TABLE NJ 6.23 EQUIVALENT LENGTH FACTORS, Le, FOR TYPICAL EMITTERS

Nominal Pipe Diameter	Le, feet
3/8”	0.9
12 mm	0.6
15 mm	0.4
½”	0.3
¾”	0.2
more than ¾”	0

Note: Assume Le = 0 for emitter spacing 20 times Le or greater. For example, assume Le = 0 for ½” pipe when emitters are spaced 6 feet (20 x 0.3) or more apart.

TABLE NJ 6.24 OUTLET CORRECTION FACTOR, Fe

Number of Outlets	Fe	Number of Outlets	Fe
1	1.00	7	0.44
2	0.65	8-11	0.42
3	0.55	12-19	0.40
4	0.50	20-30	0.38
5	0.47	31-70	0.37
6	0.45	more than 70	0.36

The friction loss in 1 ½" or larger pipe, or small tubing used to drop the pressure between a manifold and a lateral, can be calculated by the Hazen-Williams formula:

$$P= 4.53\ (Q/C)^{1.85}\ D^{-4.87}\ L$$

where: C = 140 for, polyethylene pipe

C = 150 for PVC pipe

P = pressure drop in the pipe, psi

Q = flow rate, gpm

D = pipe diameter, inches

L = pipe length, feet

Sloping Terrain

Elevation changes and their effect on pressure gain or loss must be considered in the design. A 2.3 foot change in elevation causes a change in pressure of 1 psi. Normally, laterals are run along rows that are level or nearly so. On rolling terrain, careful planning by a qualified engineer or specialist is required.

Sometimes a lateral can be designed to take advantage of a downsloping field so that the energy lost by friction balances the energy gained by the elevation drop. Often, however, to maintain uniform pressure on slopes steeper than 5%, either laterals must be shortened or pressure compensating emitters or pressure regulators must be installed.

Except on small plots less than a quarter acre or so, it is better to divide the field into several subunits or zones. Valves control watering so each zone is watered in sequence during the day. A smaller water supply, pump, and piping is required if water can be applied over a longer period instead of all at once over the entire field.

TABLE NJ 6.25 FRICTION PRE55URE LOSS FOR CONTROLLED I.D. PE PIPE[1/]

PIPE SIZE, INCHES

Q, gpm	1/2	3/4	1	1-1/4	1-1/2	2	2-1/2	3
1	0.448	0.124	0.038	0.010	0.005	0.001		
2	1.76	0.448	0.138	0.036	0.017	0.005		
3	3.72	0.948	0.293	0.077	0.036	0.011		
4	6.34	1.61	0.498	0.131	0.062	0.018		
5	9.58	2.44	0.753	0.198	0.094	0.028		
6	13.42	3.42	1.06	0.278	0.131	0.039		
7	17.85	4.54	1.40	0.370	0.175	0.052		
8	22.85	5.82	1.80	0.473	0.224	0.066		
9	28.42	7.23	2.23	0.588	0.278	0.082		
10	34.53	8.79	2.72	0.715	0.338	0.100		
11		10.48	3.24	0.853	0.403	0.119		
12		12.32	3.80	1.00	0.473	0.140		
13		14.28	4.41	1.16	0.549	0.163		
14		16.38	5.06	1.33	0.629	0.187		
15		18.61	5.75	1.51	0.715	0.212		
16		20.97	6.48	1.71	0.806	0.239		
17		23.46	7.25	1.91	0.901	0.267		
18			8.06	2.12	1.00	0.297		
19			8.90	2.34	1.11	0.328		
20			9.79	2.58	1.22	0.361	0.152	
22			11.68	3.07	1.45	0.431	0.181	
24			13.72	3.61	1.71	0.506	0.213	
26			15.91	4.19	1.98	0.587	0.247	
28			18.24	4.80	2.27	0.673	0.283	
30				5.46	2.58	0.764	.0322	
32				6.15	2.90	0.861	0.363	
34				6.88	3.25	0.964	0.406	
36				7.65	3.61	1.07	0.451	
38				8.45	3.99	1.18	0.499	
40				9.29	4.39	1.30	0.548	0.191
42				10.17	4.80	1.42	0.600	0.209
44				11.08	5.24	1.55	0.654	0.227
46				12.04	5.68	1.69	0.710	0.247
48					6.15	1.82	0.768	0.267
50					6.63	1.97	0.828	0.288
52					7.13	2.11	0.891	0.310
54					7.65	2.27	0.955	0.322
56					8.18	2.43	1.02	0.355
58					8.73	2.59	1.09	0.379

1/ For polyethylene pipe meeting ASTM-D-2239. Values are based on Hazen-Williams formula, C=140. Pressure loss in psi per 100 feet.

TABLE NJ 6.25 FRICTION PRESSURE LOSS FOR CONTROLLED [.D. PE PIPE (CONT.)1/

PIPE SIZE, INCHES

Q, gpm	2	2-1/2	3	4	6
60	2.76	1.16	0.403	0.108	
62	2.93	1.23	0.429	0.114	
64	3.11	1.31	0.455	0.121	
66	3.29	1.38	0.481	0.128	
68	3.47	1.46	0.508	0.136	
70	3.66	1.54	0.536	0.143	
75	4.16	1.75	0.610	0.162	
80	4.69	1.98	0.687	0.183	
85	5.25	2.21	0.768	0.205	
90	5.83	2.46	0.854	0.228	
95	6.45	2.72	0.944	0.252	
100	7.09	2.99	1.04	0.277	
105	7.76	3.27	1.14	0.303	0.041
110		3.56	1.24	0.330	0.045
115		3.87	1.34	0.358	0.049
120		4.18	1.45	0.388	0.053
125		4.51	1.57	0.418	0.057
130		4.85	1.69	0.449	0.061
135		5.20	1.81	0.482	0.066
140		5.56	1.93	0.516	0.070
145		5.94	2.06	0.550	0.075
150		6.32	2.20	0.586	0.080
160			2.48	0.660	0.090
170			2.77	0.738	0.101
180			3.08	0.821	0.112
190			3.40	0.907	0.124
200			3.74	0.997	0.136
220			4.46	1.19	0.162
240				1.40	0.190
260				1.62	0.221
280				1.86	0.253
300				2.11	0.288
350				2.81	0.382
400				3.60	0.490
500					0.740
600					1.04
700					1.38
800					1.77
900					2.19

1/ For polyethylene pipe meeting ASTM-D-2239. Values are based on Hazen-Williams formula, C=140. Pressure loss in psi per 100 feet.

Basic Information for Planning and Design

A map showing the size, shape, elevation contours, and distance from the water source to the area to be irrigated should be drawn. Also note such items as soil type, climate, and distance to a source of electricity.

Consider various planting arrangements as they affect production and movement through the field and to accommodate the irrigation system layout in an effective manner. The spacing of plants within the row, spacing between rows, and the choice of single or double row planting must be known to choose and size components.

Generally, irrigation laterals should be level. Typical line-source emitter tubes can be run only 200 to 300 feet. Half-inch diameter plastic laterals with point-source emitters can be 500 to 1000 feet long on level terrain.

A permanent system with above ground point-source emitters and buried pipelines is common for tree crops. Line-source emitters are used on vegetable crops and discarded at the end of the season.

An inventory and evaluation of the site should address the following:

- Field Elevations – Prepare a topographic map with 2 ft. contour intervals, showing elevations from the water source to the field. Include field shape, layout, dimensions, and elevations of key points.
- Soils – Series, texture, available water capacity, and MAD for crops grown, crop ET, area of soil to be wetted by micro system.
- Crop – type, size, location, spacing and density.
- Water source – quantity, quality, location, water measuring devices.
- Desirable emitter system and lateral lines
- Filtration system
- Mainline and submain layout, valves, and pressure gauges.
- Power supply: type and location.
- Pump – type; if submersible, depth set in well, pumping level, and column height; suction lift (centrifugal).
- Future expansion including mature tree size, interplantings of new trees, and different crops to be grown in a rotation.
- Growers desire as to level of operation and automation, management skills available, and irrigation scheduling.

Use Drip Irrigation Inventory Worksheet in NJIG Chapter 15

Design Steps

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

Step 1. Determine net depth of application, (inches).

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

Where: C = 1.604 as units conversion factor
Q = discharge rate in gph per emitter or per foot of lateral for line source
N = Number of emission devices or total length of lateral in feet.
T = Hours of operation per day (maximum 22 hrs.)
A = Areas in square feet served by number of emitters.
E = Overall field application efficiency (as a decimal, maximum .9)
f = Percent of total area to be wetted (as a decimal). Use the canopy coefficient for percent canopy shading. Refer to Table NJ 6.26 Percentages of Ground Shade and Canopy Coefficients.

Step 2. Emitter design

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

Step 4. Size laterals, submains, and mainlines.

Step 5. Determine pump size needed.

Step 6. Determine filter system needed.

Step 7. Determine fertilizer injector needs.

Step 8. Determine chlorine and acid injector needs.

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

Step 10. Provide irrigation scheduling information based on system application rates, soil AWC, MAD, and plant evapotranspiration rates (assuming no rainfall).

Step 11. Prepare irrigation system operation and maintenance plans and IWM Plan.

Design worksheets and example design spreadsheets are included in NJIG Chapter 15.

Installation

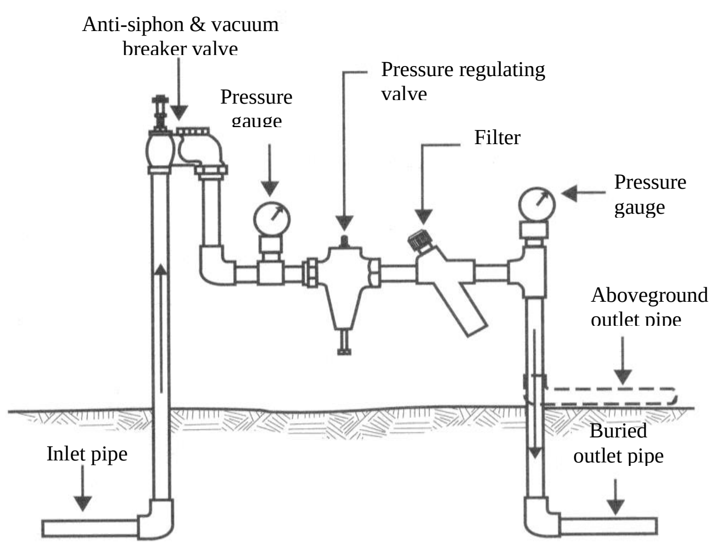
All pipelines and tubing should be designed to permit draining and flushing to remove foreign matter that can clog emitters. All pipelines should be drained to prevent freezing, algae growth, and other such problems.

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

Surface installed laterals should be snaked to allow for contraction and expansion caused by temperature change. Add 5 – 10 percent to the length for expansion and contraction (snaking). Figure NJ 6.5 displays a typical small system hookup.

Table NJ 6.26 Percentages of ground shade and canopy coefficients for orchards and vineyards

Ground Shaded (%)	10	25	50	60+
Canopy coefficient	0.3	0.6	0.9	1.0



Chapter 7

Farm Distribution Systems

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NJ652.07 Farm Distribution Systems

(a) Pipeline Delivery System

Pipeline systems are most common in New Jersey. They can be pumped or gravity flow. Generally pumped pressure pipeline is used. Buried pipeline extends from a water source to the farm and to individual fields with surface pipe used for distribution within the field. Buried pipe can also extend into fields as a field main or submain with risers and valves appropriately spaced to deliver water to sprinkler and micro irrigation systems.

A pump is used to provide adequate pressure head to overcome elevation, pipe friction losses and fitting losses and design pressures at the emission points.

Typical use includes:

- Pipe within a pumping plant system that lifts water from source to open ditch or field.
- Conveyance and Distribution System
- Pipelines to contain pressurized flows for use in sprinkler and micro irrigation systems.

Materials are generally welded steel, galvanized steel, aluminum, or plastic.

(b) Open Ditches

Field and farm ditches convey and distribute water from the source of supply (reservoir, canal, or well) to a field(s) within a farm. In New Jersey open ditches and water control structures are used on many cranberry and blueberry operations to maintain high water tables for subsurface irrigation, to flood cranberry bogs during harvest and winter months, and to provide drainage when necessary. Open ditches should be designed on a nearly level grade. Good workable grades are 0.05 - 0.2 foot per 100 feet.

Open ditches can provide good habitat for a variety of wildlife. Well vegetated ditch banks can help prevent soil erosion and at the same time be good habitat for several varieties of upland game birds.

(c) Water Control Structures

Where open ditches are used to deliver water, structures are typically needed to screen and remove trash and debris, settle and remove sediment, measure flow, divide water, control grade for erosion protection, for spill and overflow, head control, ditch checks, pipeline inlets and outlets, and to carry water under farm roads or field access points (culverts).

(d) Water Measurement

Water measurement is essential for equitable distribution of the water supply and for efficient use on the farm. Knowing *how much* water is applied is essential for proper irrigation water management. Flow measurement has other uses; for example, it can indicate when a pump impeller is becoming worn and inefficient, or when well discharge becomes reduced. Flow changes can also indicate clogged screens and filters, or partly closed or plugged valves. Water supply issues in the state of New Jersey may lead to strong recommendations that measuring devices be installed.

To accurately measure water, water measurement devices must be installed according to requirements specific to that device; operated under the conditions for which they are designed; and maintained.

There are various methods and devices each having their own flow equation or calibration process. In New Jersey, generally irrigation pipe flow is measured using flow meters (propeller, impeller). Flow meters are volumetrically calibrated at the factory for various pipe diameters. Accuracy can be within 5 percent of actual if the meter is well maintained and calibrated periodically. It is recommended they be installed downstream of a screen filter to prevent debris or sand particles from damaging the impeller, or causing malfunction. Flow meters require straight run distances (no fittings or bends in pipeline) upstream and downstream, to reduce turbulence and maintain accurate readings.

(e) Irrigation Tailwater Recovery and Reuse

Tailwater recovery and reuse (pumpback) facilities collect irrigation runoff and return it to the same or adjacent fields for irrigation use. Runoff is temporarily stored until sufficient volume has accumulated to optimize application efficiency on each succeeding irrigation.

In New Jersey tailwater recovery is becoming a common practice on container nursery operations using solid set sprinkler systems in hoophouses. Runoff has been calculated to be 70 – 80 percent of the irrigation application. This is due to the amount of open areas (not occupied by containers) that are wetted, the canopy area in the pot that deflects water from getting into the containers, and the large areas of impervious and compacted ground.

Components of tailwater recovery systems on container nursery operations consist of: water conveyance practices such as grassed or stoned lined waterways (which also control erosion), ditches, diversions, and pipelines to convey water to a central collection area (reservoir); a reservoir for water storage; a pump and power unit for recycling back to the hoophouses; a treatment system such as chlorination and filtration or ionization to kill disease spores, bacteria etc.; and pipeline to convey water for redistribution and reuse. Tailwater reuse facilities collect enough water to use as an independent supply or as a supplement to the original supply. Thus they have the most flexibility. The reservoir size depends on whether collected water is handled as an independent supply and, if not, on the rate water is pumped for reuse.

Tailwater reservoirs for hoophouse container operations should be at least 8 – 10 feet deep with side slopes 2:1 or flatter for weed control and soil stability. The reservoir should be sealed with bentonite or a plastic liner to prevent nitrate and chemical leachate into the groundwater. The reservoir should remain nearly full when not in use to help assure a positive hydraulic gradient for reservoir sealing. A sediment trap may be designed at the tailwater inflow.

Sizing for Runoff: As a rule of thumb, the minimum capacity can be designed to handle runoff from at least 1 - 2 irrigation sets (2 – 4 days of irrigation multiplied by the number of hours per day the pump is running). Expected recovery may be 65 – 80% due to seepage, evaporation, overflow, and miscellaneous losses.

As an example: A 10 acre container nursery operation's primary irrigation water supply is a well with a pumping capacity of 500 gpm. About 80% of the irrigation application runs off the hoophouse acreage, and 70% can be recovered. The irrigation run time is 8 hours, every 2 days (this only completes 5 acres). The pump must run 8 hours every day to meet crop water requirements. It is recommended that 4 irrigation days, (32 hours) are used to calculate runoff and storage capacity needed (Q).

Therefore size reservoir as follows:

Q = 500 gpm x .8 x 60 min/hr x 32 hours x .7

= 537,600 gallons storage capacity

Water quality concerns are associated with tailwater runoff and reuse. Fertilizer, chemicals, and disease pathogens are often present in the tailwater, and therefore the collected water must be treated prior to reuse. Common methods of treatment include gas chlorination (continuous) and ionization processes.

(f) Pumping Plant

The pumping plant selected must be capable of delivering the required capacity at the design operating pressure. Economy of operation is also a primary consideration and must include evaluation of the operation with the power source available. More discussions of pumping plants are contained in Chapter 8 of the NRCS National Engineering Handbook, Section 15 Irrigation. Manufacturer's representatives must also be contacted to assure that the pumping plant selected can perform in accordance with the system requirements.

The function of an irrigation system pumping plant is to perform work to move water in the amount needed and at the pressure required to meet demands of the irrigation system. Every commercially manufactured pump has a known and published relationship between head (pressure) and volume (capacity) produced. This relationship is generally plotted as a curve called the pump characteristic curve or pump performance curve. Multiple curves are used to show characteristics of different impeller diameters and impeller rotation speeds used in the same size and model pump. Pump curves are available from pump dealers, and manufacturers free of charge to designers and pump owners.

A pump operates most satisfactorily under a head and at a speed approximately that for which it was designed. The operating conditions should, therefore, be determined as accurately as possible. If there is a variation in operating head, both the maximum and the minimum should be determined and furnished to the manufacturer to permit selection of the most satisfactory pump.

An understanding of certain terms common to pump irrigation will be of value to both the irrigator and the planner. Knowledge of the terminology as it applies to selection and application of pumping equipment is equally important to the designer and the user. With the use of accurate data, the system planner can make proper selection of pumping equipment and assure the user satisfactory performance of the system.

Head and Pressure

When water is at rest, the pressure at any point in the water is due to the weight of water above the point. The height of water above the point is referred to as "head" and is expressed in feet. "Head" can be converted directly to "pressure', by multiplying "head" by an appropriate constant. To convert "head" in feet to "pressure" in pounds per square inch (psi), multiply "head" by 0.433 (Water weighs 62.4 pounds per cubic feet (pcf), so "head" (in feet) x 62.4 pcf/144 square inches per square foot = 0.433 psi). Conversely, "pressure" in psi can be converted to "head" in feet by multiplying "pressure" by 2.31. Pressures are usually measured directly with a gage.

Dynamic Head

An operating sprinkler system has water flowing through the pipes, thus the head under which the system is operating is dynamic.

Dynamic head is made up of several components, as follows:

1. Static Head - Static head is a vertical distance. It is the distance through which the pump must raise the water. Where the water source is below the pump centerline, the distance from the water surface to the pump centerline is called the static suction lift. If the pump centerline is below the water surface elevation, the distance described is termed the static suction head. Net Positive Suction Head (NPSH) is the elevation water can be raised at sea level by the suction side of the specific pump impeller. Unless the pump is self priming, the pump impeller must first be filled with water. If the allowable NPSH for a specific pump is exceeded, it will lose prime. The height of water which pushes back on the pump is called the static discharge head. It is the vertical distance from the pump centerline to the outlet pipe centerline. The outlet pipe is the pipe from which the water is discharged into the atmosphere and the outlet may be either free-flowing or constricted, such as with a sprinkler head.

   Total Static Head is the sum of the static suction lift and the static discharge head when the pump centerline is located above the water source. If the pump centerline is below the water surface elevation, the static suction head is helping the pump and is subtracted from the static discharge head.

2. Pressure Head - Sprinkler operating pressure converted to head is termed pressure head. The sprinkler converts pressure head to velocity head which carries the water out into its trajectory.

3. Friction Head - The friction caused by water flowing through a pipe decreases pressure in the pipe. The pump must overcome this loss, termed friction head, which is a function of pipe size, type, condition and length, and water velocity. Use Table NJ 6.11 to determine friction head (loss). Similar losses are incurred by water flowing through pipe fittings.

4. Velocity Head - Flowing water represents energy, and work must be done by the pump to impart motion to the water. The work required to impart movement to the water is similar in effect to friction. Velocity head is computed by squaring the velocity and dividing by two times acceleration due to gravity, or

$$Hv = \frac{V^2}{2g}$$

Velocity is measured in feet per second and can be computed from

$$V = \frac{0.408 \times gpm}{D^2}$$

Where:
gpm = discharge in gallons per minute
D = inside diameter of the pipe in inches.
Hv values are small and usually negligible unless large volumes are pumped through small diameter pipes.

5. Total Dynamic Head (T.D.H.)

This is a very important factor in selecting the pumping unit. An accurate estimate is necessary to assure satisfactory pump performance. First calculate the components discussed in the preceding paragraphs and add them together:

Total dynamic head =

total static head + pressure head + friction head + velocity head

Losses in Fittings and Valves

Allowance must be made for friction losses in all elbows, tees, crossings, reducers, increasers, adapters, and valves placed in lateral lines, main lines or submains, and in the suction line. Where deep-well turbine pumps are used, losses in the column must be considered. Pump manufacturers include allowances for losses within the pumps in pump performance data. No additional allowance for pump friction loss is needed.

Losses in fittings and valves are computed by the formula:

$$h_f = K \frac{V^2}{2g}$$

Where:

h_f = friction head loss in feet
K = resistance coefficient for the fitting or valve
$V^2/2g$ = velocity head in feet for a fitting or valve

Values of the resistance coefficient K may be taken from Table NJ 7.1 and values of $V^2/2g$ from Table NJ 7.2.

Variables contributing to the head-capacity relationship include:

- Pump make, model number, and discharge size
- Impeller type, diameter, and speed of rotation
- Number of impellers or pumps operating in series
- Net input energy required (usually expressed in brake horsepower
- Net positive suction head
- Impeller efficiency

Every pump installation has an optimum operating efficiency. The designer should strive to select pump operation at or near that efficiency. It is very unlikely that a used or even new pump at a bargain price can be obtained that fully meets the system needs without first checking the specific Head-Capacity Curve for that specific make, model, and size of pump. **Horsepower alone is an inadequate specification for selecting a pump.** Flow capacity (Q) and Total Dynamic Head (TDH) are required for pump selection.

Detailed examples of pump design are in NEH, Part 623 (Section 15), Chapter 8, Irrigation Pumping Plants, and NEH, Part 624 (Section 16), Chapter 7, Drainage Pumping. In addition pump manufacturers' catalogs and computer programs have information and design assistance on pump design and pump-head capacity characteristics. The National Irrigation Guide, Chapter 15 gives information on interpreting pump curves, and Chapter 11 has information about cost analysis for irrigation systems.

Example: The following example shows how head is determined for centrifugal pumps. Refer to Figure NJ 7.1 for layout sketch.

Problem: Check total dynamic suction lift and total dynamic head.

A.	Compute total dynamic suction lift:	FEET
1.	Static suction lift	13.00
2.	Friction head in pipelines:	
	From Table NJ 6.11, 5" aluminum pipe at 500 gpm, loss = 5.04 ft/100 ft.	
	Suction pipe = (25' + 10') = 35' 35' of 5" pipe at 500 gpm = 35' x 0.0504 ft./ft	1.76
3.	Velocity head $V^2/2g$ (Table NJ 7.2)(5" @ 500 gpm)	1.13
4.	Friction head in fittings (use Tables NJ 7.1 and NJ 7.2):	
	5-inch 45° long radius bend ($h_f = K \times V^2/2g$ = 0. 18 x 1.127)	0.21
	Foot valve ($h_f = K \times V^2/2g$ = 0.8 x 1. 127)	0.90
	Strainer ($h = K \times V^2/2g$ = 0.95 x 1.127)	1.07
	Total Suction Lift	18.07

New Jersey is near sea level so this is an acceptable value for suction lift.

B.	Compute total dynamic discharge head:	FEET
1.	Static discharge head	30.00
2.	Friction head in pipelines (use Table NJ 6.11):	
	400' of 6" pipe at 500 gpm = 400 x .02047	8.19
	300' of 5" pipe at 500 gpm = 300 x .05039	15.12
3.	Friction head in fittings (use Tables NJ 7.1 and NJ 7.2):	
	One 5" to 6" increase $K = (1-5^2/6^2)^2 = 0.093$	

($h_f = K \times V^2/2g = 0.093 \times 1.127$) 0.11

One 6" standard flanged 900 elbow

($h_f = K \times V^2/2g = 0.28 \times 0.54$) 0.15

One 6” gate valve, open

($h_f = K \times V^2/2g = 0.11 \times 0.54$) 0.06

Five 611 takeoff valves
(same as gate valve open: 0.11 x 0.54 x 5) 0.30

Four 5” takeoff valves
(same as gate valve open: 0.13 x 1.127 x 4) 0.73

One tee, branch flow
($h_f = K \times V^2/2g = 0.65 \times 1.127$) 0.14

One 6” to 5” reducer $K = 0.7(l - 5^2/6^2)^2 = 0.065$
($h_f = K \times V^2/2g = 0.065 \times 1.127$) 0.07

4. Velocity head at end of discharge pipe

(5” pipe at 500 gpm) 1.13

5. Pressure required to operate lateral (50 psi x 2.31’) 115.50

Total Discharge Head 171. 50

T.D.H. = Total dynamic suction lift + total dynamic discharge head - suction velocity head
= 18.07 + 17 1.50 - 1.13 = <u>190.7 feet</u>

The pump selected should be capable of discharging 500 gpm at 191 feet of head.

<u>Pumps</u>

The output work required of the pump is expressed in water horsepower. Water horsepower can be determined by the following equation:

$$\text{Water Horsepower} = \frac{\text{gpm} \times \text{T.D.H}}{3960}$$

Water horsepower is a measure of the output of a pump. However, pumps are not 100% efficient. Pump efficiency depends on the type of pump, bearings, materials, water temperature, and discharge. The pump is connected to the motor through a drive system. Direct drive systems are nearly 100% efficient, but other drive systems are less efficient. Manufacturers of pumps and drive systems provide performance data, including efficiency, for their products.

Power Source

The power source must supply the required water horsepower, plus the losses due to inefficiencies in the pump and drive system. The required output of the power source is called brake horsepower (BHP) and can be computed by the following equation:

$$BHP = \frac{\text{gpm} \times \text{T.D.H.}}{3960 \times \frac{\text{Drive efficiency}}{100} \times \frac{\text{Pump efficiency}}{100}}$$

Example: The system requires 500 gpm at 191 feet total dynamic head. If a direct drive system is used with a centrifugal pump which operates at 73% efficiency, the minimum required brake horsepower would be:

$$BHP = \frac{500 \text{ gpm} \times 191 \text{ ft. T.D.H.}}{3960 \times \frac{100}{100} \times \frac{73}{100}}$$

$$BHP = 33.0$$

The power source must be able to supply the required BHP under field conditions, which may be severe, and under continuous operation. Electric motors are usually rated for continuous operation, but may need to be derated for high temperature (hotter than 95^0F) or high altitude conditions.

Internal combustion engines are often not rated for continuous use. Automotive and lightweight industrial engines are usually rated for "peak" power output, and must be derated substantially (typically 40%) for continuous use. Heavy duty industrial, agricultural and farm tractor engines are usually rated for "intermittent" use, and must also be derated (15 - 20%) for continuous use. Internal combustion engines are more sensitive to altitude and temperature than electric motors, so careful attention must be given to actual field conditions and the manufacturers engine performance recommendations. Power allowance must also be made for engine accessories, such as the water pump, fan, alternator, etc.

Example: For the above example, suppose that a diesel engine will supply the power. The engine is rated for intermittent use at sea level and 60 degree F. Field conditions will be 90 degree F and near sea level (New Jersey). The following power corrections must be made: for continuous operation, 20%; accessories, 5%; temperature (use 1% for each 10 degree F change), 3%. Total correction is 28%:

$$Bhp = \frac{33.0 \text{ bhp}}{1.00 - 28/100} = 45.8 \text{ bhp.}$$

The engine must be rated for at least 46 bhp.

The pump and power source must not be under-sized, because poor performance and unreliability will result. Also, normal wear of the pump and power source will reduce efficiencies. However, over-sizing should also be avoided, because over-sizing increases initial costs, reduces operating efficiencies, and thereby increases costs overall.

Figure NJ 7.1 Typical Centrifugal Pump System

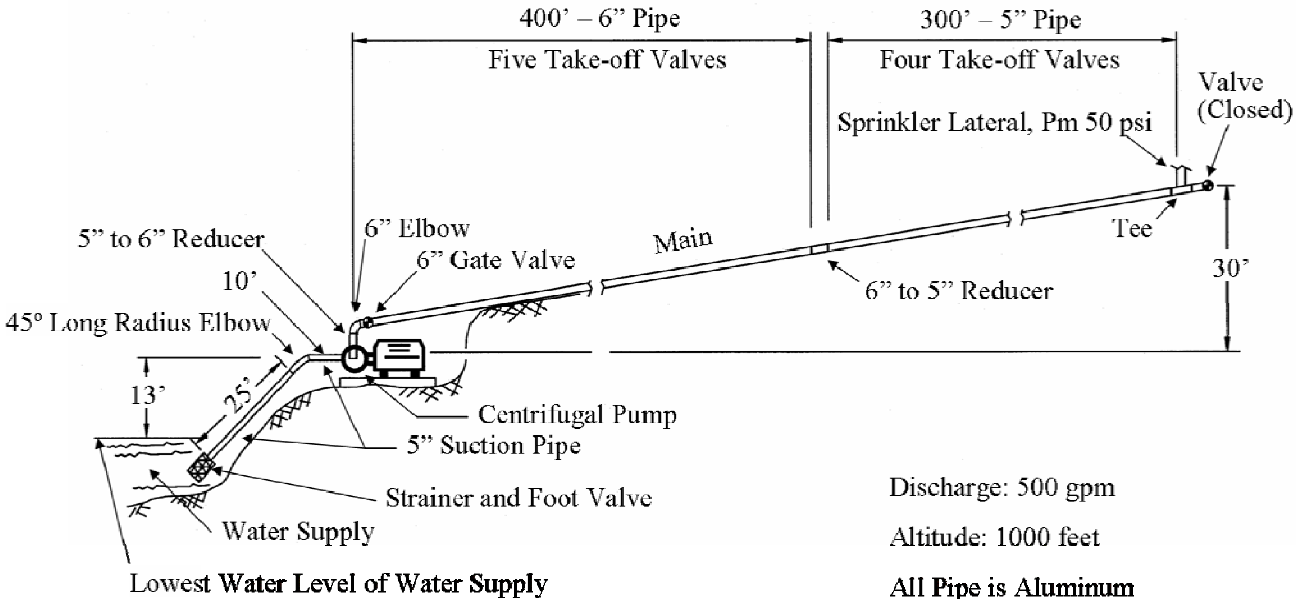

TABLE NJ 7.1 VALUES OF RESISTANCE COEFFICIENT K FOR FITTINGS AND VALVES

Fitting or Valve	Nominal Diameter 3-in	4in	5-in	6-in	7-in	8in	10-in	Source of Authority
				STANDARD PIPE				
Elbows:								
Regular flanged 90^0	0.34	0.31	0.30	0.28	0.27	0.26	0.25	Pipe Friction Manual
Long radius flanged 90^0	0.25	0.22	0.20	0.28	0.17	0.15	0.14	Hydraulic Institute
Long radius flanged 45^0	0.19	0.18	0.18	0.17	0.17	0.17	0.16	Same as above
Regular screwed 90^0	0.80	0.70						Same as above
Long radius screwed 90^0	0.30	0.23						Same as above
Regular screwed 45^0	0.30	0.28						Same as above
Bends:								
Return flanged	0.33	0.30	0.29	0.28	0.27	0.25	0.24	Pipe Friction Manual
Return screwed	0.80	0.70						Hydraulic Institute
Tees:								
Flanged line flow	0.16	0.14	0.13	0.12	0.11	0.10	0.09	Same as above
Flanged branch flow	0.73	0.68	0.65	0.60	0.58	0.56	0.52	Same as above
Screwed line flow	0.90	0.90						Same as above
Screwed branch flow	1.20	1.10						Same as above
Valves:								
Globe flanged	7.0	6.3	6.0	5.8	5.7	5.6	5.5	Same as above
Globe screwed	6.0	5.7						Same as above
Gate flanged	0.21	0.16	0.13	0.11	0.09	0.075	0.06	Same as above
Gate screwed	0.14	0.12						Same as above
Swing check flanged	2.0	2.0	2.0	2.0	2.0	2.0	2.0	Same as above
Swing check screwed	2.1	2.0						Same as above
Angle flanged	2.2	2.1	2.0	2.0	2.0	2.0	2.0	Same as above
Angle screwed	1.3	1.0						Same as above
Foot	0.80	0.80	0.80	0.80	0.80	0.80	0.80	Same as above
Strainers-basket type	1.25	1.05	0.95	0.85	0.80	0.75	0.67	Same as above
				OTHER				
Inlets or entrances:								
Inward projecting	0.78	All diameters						King's Handbook
Sharp cornered	0.50	All diameters						King's Handbook
Slightly rounded	0.23	All diameters						King's Handbook
Bell-mouth	0.04	All diameters						King's Handbook
Sudden enlargements	$K = (1 - d_1^2/d_2^2)^2$ where d_l = diameter of smaller pipe							S.I.A. Handbook
Sudden enlargements	$K = 0.7(1 - d_1^2/d_2^2)^2$ where d_l = diameter of smaller pipe							S.I.A. Handbook

I/ For use in formula $h_f = K\ V^2/2g$

TABLE NJ 7.2-VALUES OF VELOCITY HEAD $\frac{V^2}{2g}$ FOR ALUMINUM PIPE, IN FEET

Flow (gallons per minute)	3 in (2.914)	4-in (3.906)	5-:in (4.896)	6-in (5.884)	7-in (6.872)	8-in (7.856)	10-inch (9.818)
50	0.090	0.028					
100	0.359	0.111	0.045	0.021			
150	0.809	0.250	0.101	0.049			
200	1.438	0.445	0.180	0.086	0.046		
250	2.246	0.696	0.282	0.135	0.085		
300	3.235	1.002	0.406	0.195	0.105	0.061	
350	4.402	1.364	0.552	0.265	0.142	0.083	
400	5.750	1.781	0.722	0.346	0.186	0.109	0.044
450		2.255	0.913	0.438	0.235	0.138	0.056
500		2.783	1.127	0.540	0.290	0.170	0.070
550		3.368	1.364	0.654	0.351	0.206	0.084
600		4.008	1.623	0.778	0.418	0.245	0.100
650		4.704	1.906	0.913	0.491	0.287	0.118
700		5.455	2.210	1.059	0.569	0.333	0.137
750		6.262	2.537	1.216	0.654	0.383	0.157
800			2.886	1.384	0.744	0.435	0.178
850			3.258	1.562	0.840	0.492	0.201
900			3.653	1.751	0.941	0.551	0.226
950			4.070	1.951	1.049	0.614	0.252
1000			4.510	2.162	1.162	0.680	0.279
1100			5.457	2.616	1.406	0.823	0.337
1200			6.494	3.113	1.673	0.980	0.402
1300				3.654	1.964	1.150	0.471
1400				4.238	2.278	1.333	0.347
1500				4.865	2.615	1.531	0.627
1600				5.535	2.975	1.742	0.714
1700				6.248	3.358	1.966	0.806
1800					3.765	2.204	0.904
1900					4.195	2.456	1.007
2000					4.648	2.722	1.116

Chapter 8

Project and Farm Irrigation Water Requirements

Contents **NJ652.08**

NJ652.08 Project and Farm Irrigation Water Requirements

This chapter focuses on water supplied by an offsite group to multiple farms within an irrigation project area. An irrigation project area is defined as blocks of irrigated land within a defined boundary, developed or administered by a group or agency. This chapter provides concepts that illustrate the use of irrigation water requirement principles when planning and designing irrigation water distribution and scheduling systems. This concept has not become an issue in New Jersey since most farms have individual water supplies which do not limit operation of on-farm irrigation systems. For detailed project irrigation water requirements refer to Chapter 8, National Irrigation Guide.

Chapter 9 Irrigation Water Management

Contents **NJ652.09**

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NJ652.09 Irrigation Water Management

(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 the waste of water, soil, plant nutrients, or energy. It means applying water according to crop needs in amounts that can be held in the soil available to crops and at rates consistent with the intake characteristics of the soil and the erosion hazard of the site.

Management is a prime factor in the success of an irrigation system. 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
- Prevent irrigation induced erosion
- Reduce labor
- Minimize pumping costs
- Maintain or improve quality of ground water and downstream surface water
- Increase crop biomass yield and product quality

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

- Applying the use of water budgets or balances to identify potential water application improvements.
- Applying the knowledge of soil characteristics for water release, allowable irrigation application rates, available water capacity, and water table depths
- Applying the knowledge of crop characteristics for water use rates, growth characteristics, yield and quality, rooting depths, and allowable plant moisture stress levels.
- Water delivery schedule effects
- Water flow measurement for on field water management
- Irrigation scheduling techniques
- Irrigation system evaluation techniques

(b) Irrigation Water Management Concepts

The simplest and basic irrigation water management tool is the equation:

$$QT = DA$$

Where:

Q = flow rate (ft^3/s)
T = time (hr)
D = depth (in)
A = area (acres)

For example, a flow rate of 1 cfs for 1 hour = 1 inch depth over 1 acre. This simple equation modified by an overall irrigation efficiency, can be used to calculate the daily water supply needs by plants, number of acres irrigable from a source, or the time required to apply a given depth of water from an irrigation well or diversion. Typically over 80 percent of IWM concerns can be at least partly clarified by the application of this equation.

When to Irrigate: This is dependent on the crop water use rate, (sometimes referred to as irrigation frequency). This can be determined by calculation of ETc rate for a specific crop stage of growth, monitoring plant moisture stress levels, monitoring soil water depletion and rainfall events. Applied irrigation water should always be considered supplemental to rainfall events. The irrigation decisionmaker should leave between 0.5 and 1.0 inch of available water capacity in the soil profile unfilled for storage of potential rainfall. Rainfall probability during a specific crop growing period and the level of risk to be taken must be carefully considered by the irrigation decisionmaker.

Water Measurement: A key factor in proper irrigation water management is knowing how much water is available to apply or is being applied to a field through an irrigation application system. Many devices are available to measure pipeline or open channel flows. Too many irrigators consider water measurement a regulation issue and an inconvenience. Typically less water is used where adequate flow measurement is part of the water delivery system.

(c) Soil-Plant-Water Balance

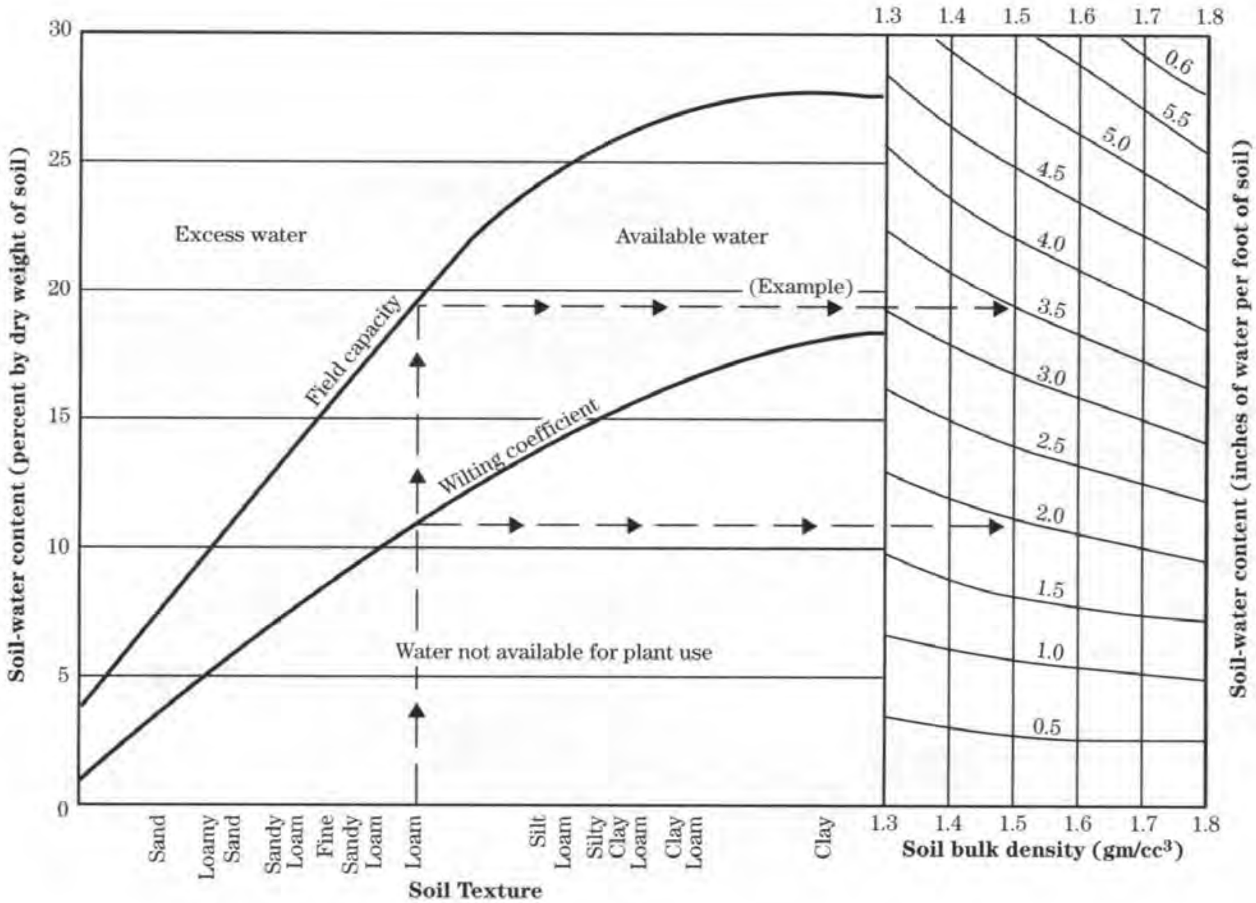
This is described as the daily accounting of water availability to the crop within its effective root zone.

Soil: Soil intake characteristics, field capacity, wilting point, available water capacity, water holding capacity, management allowed depletion, and bulk density, are soil characteristics that the irrigator must take into account to implement proper irrigation water management. Also see Chapter 2, Soils, and Chapter 17, Glossary.

- Field Capacity (FC): Defined as the amount of water remaining in the soil when the downward water flow form gravity becomes negligible. It occurs soon after an irrigation or rainfall event fills the soil. About 10 centibars soil water tension (0.1 atmosphere or bar), for sandy soils, and 30 centibars for medium to fine textured soils.
- Wilting Point (WP): Defined as the soil-water content below which plants cannot obtain sufficient water to maintain plant growth and never totally recover. Generally wilting point is assumed to be 15 atms (bar) tension.
- Available Water Capacity (AWC) is the portion of water in the soil (plant root zone) that can be absorbed by plant roots. It is the amount of water released between field capacity and permanent wilting point. Average available water capacities are displayed in Table NJ 9.1. Average soil-water content based on various textures and bulk density is displayed in Figure NJ 9.1.

- Soil-Water Content (SWC) is the water content of a given volume of soil at any specific time. This is the water content that is measured by most soil-water content measuring devices. Amount available to plants then is SWC – WP.
- Management Allowed Depletion (MAD) is the desired soil-water deficit at the time of irrigation. It can be expressed as the percentage of available soil-water capacity or as the depth of water that has been depleted in the root zone. Providing irrigation water at this time minimizes plant water stresses that could reduce yield and quality.
- Bulk Density is the mass of dry soil per unit bulk volume. It is the oven dried weight of total material per unit volume of soil, exclusive of rock fragments 2mm or larger. The volume applies to the soil near field capacity water content. To convert soil water content on a dry weight basis to volumetric basis, soil bulk density must be used.

Figure NJ 9.1 Total soil-water content for various soil textures with adjustment for changes in bulk density



The rate of decrease in soil-water content is an indication of plant water use and evaporation, which can be used to determine **when to irrigate and how much to apply.** This is the basic concept in scheduling irrigations.

TABLE NJ 9.1 AVAILABLE WATER CAPACITY FOR VARIOUS SOIL TEXTURES

Soil texture	Estimated in/in	AWC in/ft
Sand to fine sand	0.04	0.5
Loamy sand to loamy fine sand	0.08	1.0
Loamy fine sands, loamy very fine sands, fine sands, very fine sands	0.10	1.2
Sandy loam, fine sandy loam	0.13	1.6
Very fine sandy loam, silt loam, silt	0.17	2.0
Clay loam, sandy clay loam, silty clay loam	0.18	2.2
Sandy clay, silty clay, clay	0.17	2.0

Measuring Soil-Water Content: To measure soil-water content change for the purpose of scheduling irrigation, monitoring should be done at several locations in each field and at different soil depths (6" increments). Most devices used indicate relative soil-water values and are difficult to calibrate to relate to specific quantitative values. A calibration curve for each specific kind of soil and soil-water content (tension) should be available with the device or needs to be developed. Methods and devices to measure or estimate soil-water content include:

- Soil Feel and Appearance Method: Soil samples are collected at desired depths and compared to tables or pictures that give moisture characteristics of different soil textures. Refer to NRCS color publication, *Estimating Soil Moisture by Feel and Appearance*. How soil samples taken in the field from appropriate locations and depths feel and look gives some indication of moisture content. A shovel can be used to get samples, but for some soils a soil auger or a sampling tube is better. The appearance and feel of a handful of soil that has been squeezed very firmly can be compared with descriptions in a guide of estimated available-moisture content for different soil textures and conditions. Table NJ 9.2 is a guide that has been used for some time. The feel and appearance method is one of the cheapest and easiest methods to use for estimating water content, but it does require some work to get soil samples. Although this method is not the most accurate, with experience and judgment the irrigator should be able to estimate the moisture level within a reasonable degree of accuracy.

TABLE NJ 9.2 PRACTICAL INTERPRETATION CHART ON SOIL MOISTURE FOR SOIL TEXTURES AND CONDITIONS

AVAILABLE MOISTURE IN SOIL	FEEL OR APPEARANCE OF SOIL			
	COARSE-TEXTURED SOILS	MODERATELY COARSE TEXTURED SOILS	MEDIUM-TEXTURED SOILS	FINE AND VERY FINE TEXTURED SOILS
0 percent	Dry, loose, and single-grained; flows through fingers.	Dry and loose; flows through fingers	Powdery dry; in some places slightly crusted but breaks down easily into powder	Hard, baked, and cracked; has loose crumbs on surface in some places
50 percent or less	Appears to be dry; does not form a ball under pressure[1]	Appears to dry; does not form a ball under pressure[1]	Somewhat crumbly but holds together under pressure.	Somewhat pliable; balls under pressure[1]
50 to 75 percent.	Appears to be dry; does not form a ball under pressure[1]	Balls under pressure but seldom holds together.	Forms a ball under pressure; somewhat plastic; slicks slightly under pressure.	Forms a ball; ribbons out between thumb and forefingers.
75 percent to field capacity.	Sticks together slightly; may form a very weak ball under pressure.	Forms weak ball that breaks easily; does not slick.	Forms ball; very pliable; slicks readily if relatively high in clay.	Ribbons out between fingers easily; has a slick feeling
At field capacity(100 percent)	On squeezing, no free water appears on soils but wet outline of ball is left on hand.	Same as for coarse-textured soils at field capacity	Same as for coarse- textured soils at field capacity.	Same as for coarse-textured soils at field capacity.
Above field capacity	Free water appears when soil is bounced in hand	Free water is released with kneading	Free water can be squeezed out	Puddles; free water forms on surface

1/ Ball is formed by squeezing a handful of soil very firmly.

- Gravimetric or Oven Dry Method: Soil samples are collected using a core sampler. Samples must be protected from drying before they are weighed. Samples are taken to the office work room, weighed (wet weight), oven dried, and weighed again (dry weight). An electric oven takes 24 hours at 105 degrees Celsius to adequately remove soil water. Percentage of total soil-water content on a dry weight basis is computed. To convert to a volumetric basis, the percentage water content is multiplied by the soil bulk density. Available soil water is calculated by subtracting percent total soil water at wilting point. This procedure is the most accurate method for determining the soil water content, but is time consuming and may be impractical for most farmers.

The following equipment is required:

(1) Moisture proof seamless aluminum or tin sample boxes (cans) with a capacity of 3 ounces or more to contain sample for drying.

(2) Beam balance with a minimum of 500-gram capacity, accurate to 0.1 gram.

(3) Drying oven, with thermometer, capable of maintaining a temperature of 2200 F to 2400F. (105ºC to 115ºC).

(4) A core soil sampler to take bulk density samples. Alternatively, the bulk density can be determined by the sand cone method or water balloon method.

Procedure:

(1) Collect a representative soil sample of known volume using a core sampler.

(2) Determine the wet weight of the sample (WW).

(3) Dry the sample in the oven at 105^0C to 115^0C until it attains a constant weight. This will take about 24 hours. Check the weight at one hour intervals near the end of the 24 hour period. When there is no weight change, the sample is dry.

(4) Determine the dry weight of the sample (DW). Remember to deduct the tare weight of the container when determining wet weight and dry weight.

(5) Compute the bulk density (BD) and total soil water content (TSWC):

$$BD = \frac{DW(g)}{\text{Sample Volume (cc)}} \quad \text{(dry weight basis)}$$

Weight of water lost,

$$WAT = WW - DW$$

Percent Water Content (dry weight basis),

$$WC = \frac{WAT}{DW} \times 100$$

$$TSWC = \frac{BD \times WC}{100} \quad \text{(inches water per inch soil depth)}$$

(6) The total soil water content (TSWC) includes moisture that is not available to the plant at the permanent wilting point. The permanent wilting point (Pw), the

point at which a plant can no longer obtain enough soil water to meet transpiration needs, occurs at 15 atmospheres of tension and is normally determined in the laboratory. When laboratory data are not available, one of the following procedures can be used to estimate the wilting point.

(a) This procedure requires knowledge of the percent clay, less any clay size carbonate particles, of the soil being measured. For many soils, this procedure will provide a close estimate of the wilting point. The wilting point is calculated with use of the following equation:

$$Pw = 0.4 \times \text{clay } (\%)$$

Where:

Pw is the wilting point, using the clay content, expressed as percent of water on a dry weight basis.

(b) This procedure can be used where only the soil texture is known. The values given represent and average wilting point for the given texture.

Texture	Pw
Clay	25
Silty clay	19
Sandy clay	17
Silty clay loam	13
Clay loam	13
Sandy clay loam	11
Silt loam	5.5
Loam	7
Very fine sandy loam	4
Fine sandy loam	4
Sandy loam	4
Loamy fine sand	3
Loamy sand	3
Fine sand	2
Sand	2

Pw is expressed as percent water on a dry weight basis. The values given do not apply to soils having soil fragments larger than 2.0 millimeters.

(7) To determine the soil water content (SWC), Pw percentage is first converted to inches of water (WP). WP is then subtracted from TSWC to obtain SWC.

$$WP = \frac{BD \times Pw}{100} \text{ (inches water per inch soil depth)}$$

$$SWC = TSWC - WP \text{ (inches/inch soil depth)}$$

To determine the SWC for a given increment of depth, multiply SWC by the depth, in inches, being evaluated.

To determine the available water capacity (AWC) for soils not listed in Chapter 2, or for a special case where the data in Chapter 2 are not satisfactory, it is necessary to make soil water content measurements at field capacity. These measurements are made after an irrigation or effective rainfall. Before making the measurements, allow about 24 hours for sand and about 48 hours for clay for the gravitational water to drain. Determine AWC using the above procedure, where SWC becomes AWC.

Figure NJ 9.2 Soil-water content worksheet (gravimetric method)

U.S. Department of Agriculture
Natural Resources Conservation Service

Worksheet
Soil-Water Content
(Gravimetric Method)

Land user ____________ Date ________ Field office ____________

Taken by ____________ Field name/number ____________

Soil name (if available) ____________ Crop ____________ Maximum effective root depth ________ ft

Depth range inches	Soil layer thickness inches d	Soil texture	Sample			Tare weight g Tw	Net dry weight g Dw	Volume of sample cc Vol	Moisture per-centage % Pd	Bulk density g/cc Dbd	Soil-water content in/in SWC	Layer water content inches TSWC
			Wet weight g WW	Dry weight g DW	Water loss g Ww							

Dry weight (Dw) of soil = DW - TW = ________g Weight of water lost (Ww) = WW - DW = ________g Bulk density (Dbd) = $\frac{Dw(g)}{Vol\ (cc)}$ = ________g/cc

Percent water content, dry weight Pd = $\frac{Ww \times 100}{Dw}$ = ________% Soil-water content (SWC) = $\frac{Dbd \times Pd}{100 \times 1}$ = ________in/in

Total soil-water content in the layer (TSWC) = SWC x d = ________inches

- **Chemical Drying Method** (Speedy Moisture Tester) This method of drying soil samples is based on the principle that a given quantity of moisture, when combined with calcium carbide, will react to produce a specific volume of gas (acetylene). By applying this principle, a device known as the Speedy Moisture Tester was developed in England and is commercially available. It confines in a cylindrical pressure chamber the gas produced from this reaction. One end of the pressure chamber is equipped with a cap for inserting the carbide and soil sample and a clamping arrangement to confine the gas during the test. The gas pressure is read on a gage located on the other end of the pressure chamber. The gage is calibrated for a 26-gram wet weight sample of soil and the reading can be converted readily to a dry weight moisture percentage by use of a calibration curve supplied with the instrument, or by use of the conversion chart in Chapter 16.

The calcium carbide gas pressure method is a quick and reasonably accurate way of determining the moisture content of a soil. The time required to dry a sample is about 3 minutes. Its simplicity of use is such that anyone can become proficient enough in a short time to make its use a routine operation.

Care must be taken in measuring the 26-gram soil sample. When the test is finished, examine the sample for lumps. If the soil was not completely broken down by the steel balls, retest and increase the shake-and-rest time by one minute. The calcium carbide gas pressure method should not be used on saturated highly organic soils.

- **Tensiometers**: Soil-water potential (tension) is a measure of the amount of energy with which water is held in the soil. Tensiometers work on the principle that a partial vacuum is created in a closed chamber when water moves out through a porous ceramic tip to the surrounding soil. Tension is measured by a water manometer, a mercury manometer, or a vacuum gage. The scales are generally calibrated in either hundredths of an atmosphere or in centimeters of water. Tensiometers that utilize a mercury manometer are usually preferred as research tools because they afford great precision. Because of their simplicity, tensiometers equipped with Bourdon vacuum gages are better suited to practical use and to irrigation control.

After the cup is placed in the soil at the desired depth, the instrument must be filled with water. Water moves through the porous cup until the water in the cup and the water in the soil reach equilibrium.

Any increase in tension that occurs as the soil dries causes the vacuum-gage reading, which can be read above ground, to increase. Conversely, an increase in soil-water content reduces tension and lowers the gage reading. The tensiometer continues to record fluctuations in soil-water content unless the tension exceeds 0.85 atmosphere, at which point air enters the system and the instrument ceases to function. Then after an irrigation or rain, the instrument must again be filled with water before it can operate.

Some experience is required to use a tensiometer. If air enters the unit through any leaks at the rubber connections, measurements are not reliable. Air leaks can result from faulty cups. They may occur also at the contact points of the setscrews used to secure the porous cup to the metal support. Some manufacturers provide a test pump that can be used to test the gage and to remove air from the instrument.

Tensiometers readings reflect soil-moisture tension only; that is, they indicate the relative wetness of the soil surrounding the porous tip. They do not provide direct information on the amount of water held in the soil. Tension measurements are useful in deciding when to irrigate, but they do not indicate how much water should be applied. A special moisture-characteristic curve for the particular soil is needed to convert moisture-tension measurements into available-moisture percentages. Typical curves for soils are shown in Figure NJ 9.3.

Table NJ 9.3 Guidelines for using soil moisture tension data to schedule irrigation events.

	25% MAD (cb)	50% MAD (cb)
Coarse Sand	12	20
Sand	12	20
Fine Sand	12	20
Loamy Sand	15	25
Loamy Coarse Sand	15	25
Loamy Fine Sand	15	25
Loamy Very Fine Sand	20	40
Sandy Loam	20	40
Fine Sandy Loam	25	50
Very Fine Loam	25	50
Loam	30	60
Silt Loam	40	85
Sandy Clay Loam	40	85
Clay Loam	45	90
Silty Clay Loam	45	90
Sandy Clay	50	95
Silty Clay	50	95
Clay	50	95

cb = Centi bars

Tensiometers do not satisfactorily measure the entire range of available moisture in all soil types. But they probably are the best field instruments to use to determine moisture conditions in the wet range. They are best suited to use in sandy soils, since in these soils a large part of the moisture available to plants is held at a tension of less than I atmosphere. Tensiometers are less well suited to use in fine-textured soils, which hold only a small part of the available moisture at a tension of less than 1atmosphere.

Tensiometers installed at different rooting depths have different gauge readings because of soil water potential change in rooting depths. With uniform deep soil, about 70 – 80% of soil moisture withdrawal by plant roots is in the upper half of the rooting depth. Recommended depths for setting tensiometers are given in Table NJ 9.4.

Table NJ 9.4 Recommended depths for setting tensiometers

Plant root zone depth (in)	Shallow tensiometer (in)	Deep Tensiometer (in)
18	8	12
24	12	18
36	12	24
>48	18	36

Installing tensiometers must be done carefully and good maintenance is required for accurate and reliable results. They also must be protected against freeze damage. Maintenance kits that include a hand vacuum pump are required for servicing tensiometers. The hand pump is used to draw out air bubbles from the tensiometer and provide an equilibrium in tension. Tensiometers should be installed in pairs at each site, at one-third and two-thirds of the crop rooting depth. A small diameter auger (or 1/2” steel water pipe) is required for making a hole to insert the tensiometer. Figure NJ 9.4 shows a tensiometer and gauge and illustrates installation and vacuum pump servicing.

Figure NJ 9.3 Water retention curves for several soils plotted in terms of percent available water removed

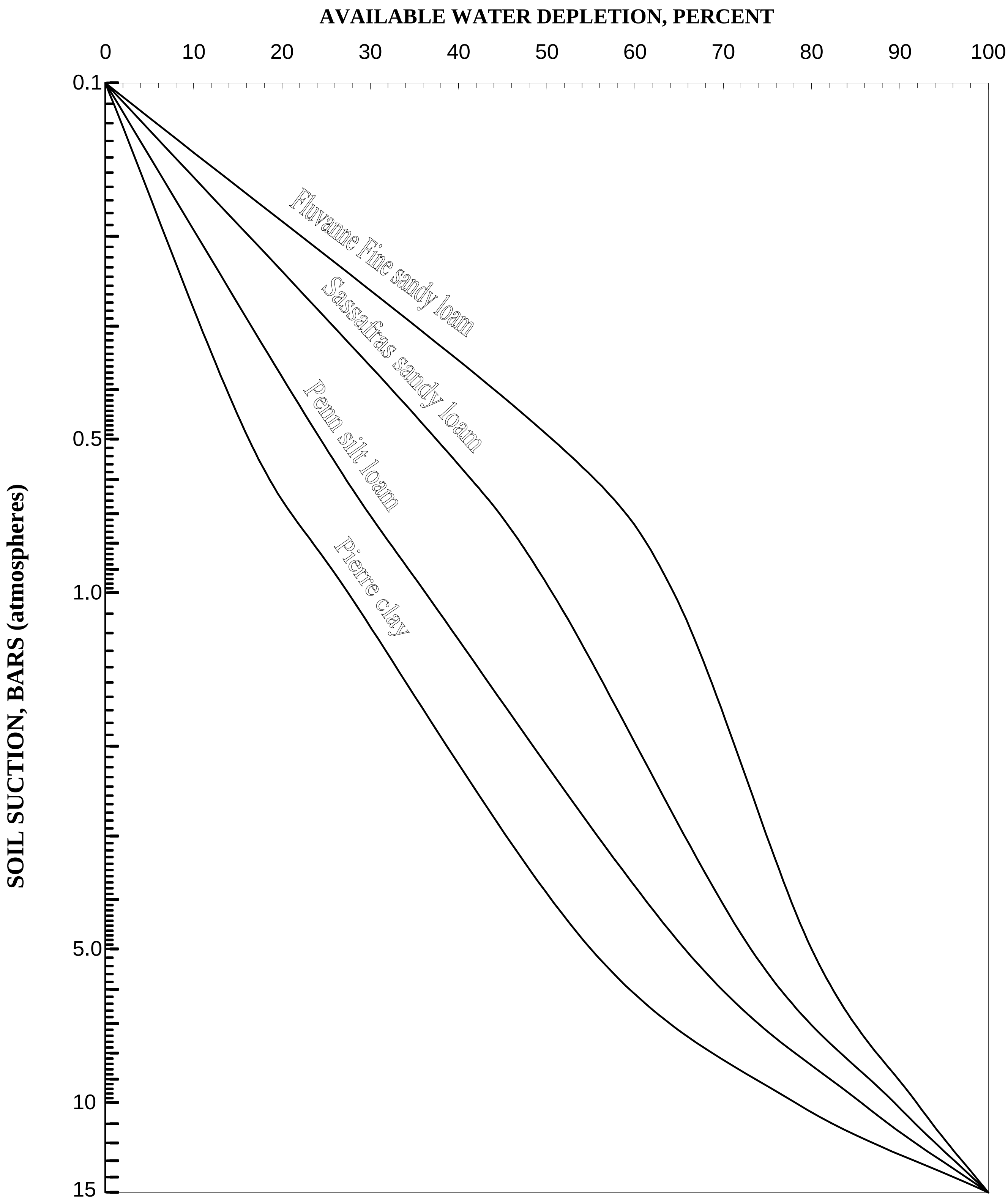
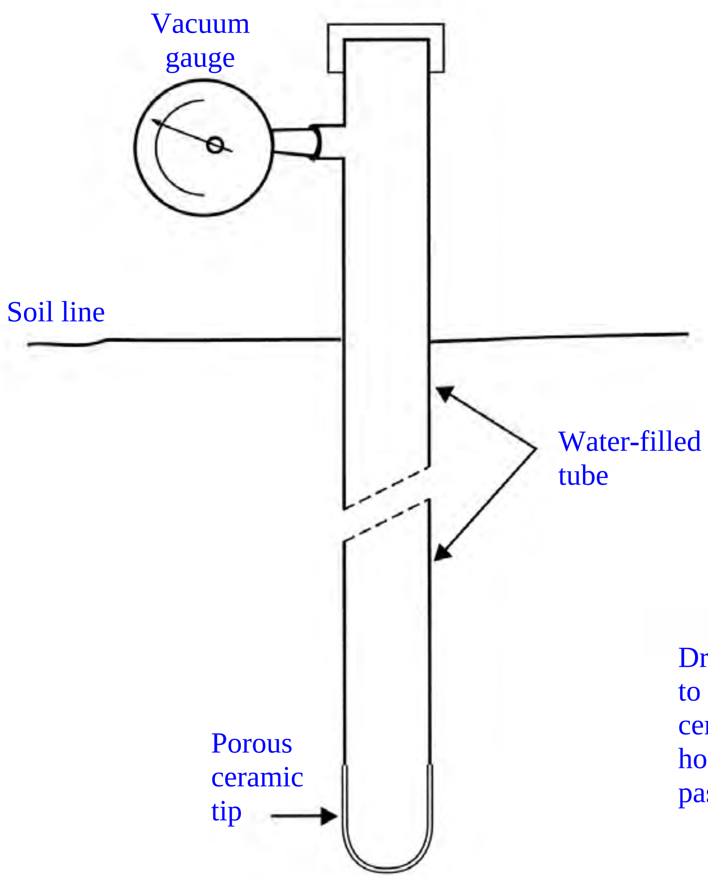
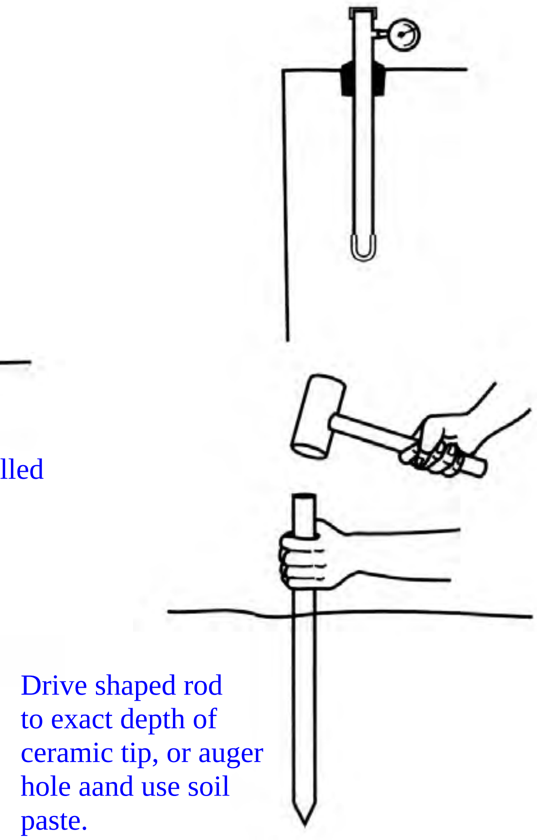
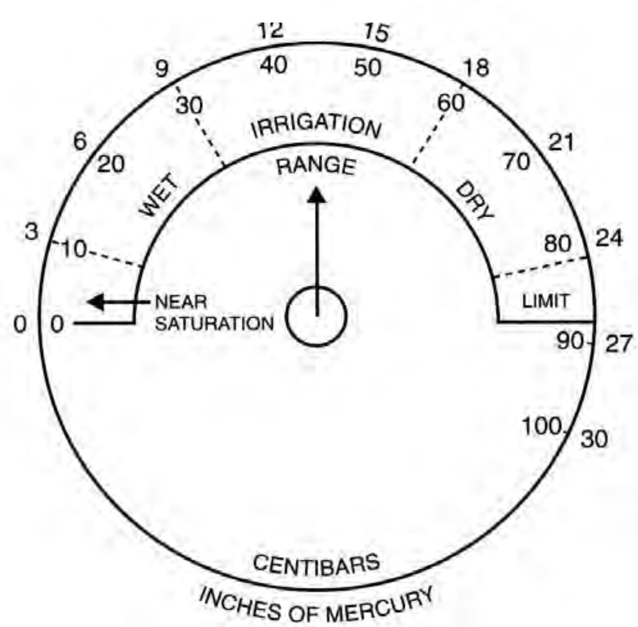


Figure NJ 9.4 Tensiometer, installation, guage, and servicing

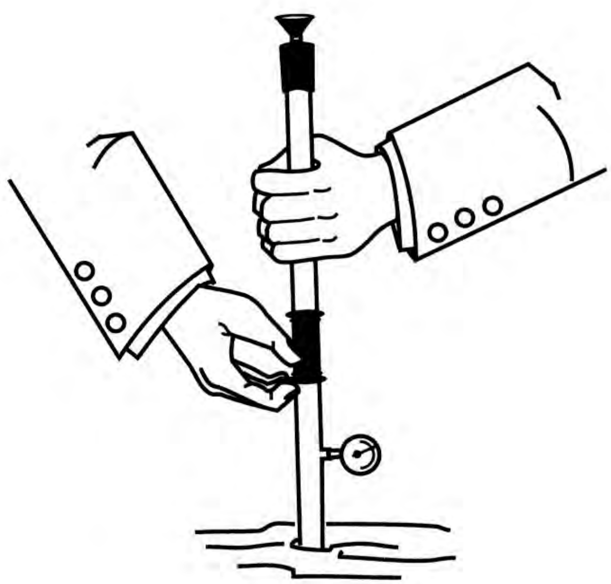




Installation procedure



Vacuum guage



Servicing tensiometer using
a vacuum pump

Electrical-Resistance Instruments:
These instruments use the principle that a change in moisture content produces a change in some electrical property of the soil or of an instrument in the soil. They consist of two electrodes permanently mounted in conductivity units, usually blocks of plaster of paris, nylon, fiberglass, gypsum, or combinations of these materials. Electrodes in the blocks are attached by wires to a resistance or conductance meter that measures changes in electrical resistance in the blocks. When the units are buried in the soil, they are in close contact with soil particles and respond to changes in soil moisture content. Since the amount of moisture in the blocks determines electrical resistance, measurement of any change in resistance is an indirect measure of soil moisture if the block is calibrated for a particular soil.

Nylon and fiberglass units are more sensitive in the higher ranges of soil moisture than plaster of paris blocks, but often their contact with soil that is alternately wet and dry. is not very good. Nylon units are most sensitive at a tension of less than 2 atmospheres. Plaster of paris blocks function most effectively at a tension between I and 15 atmospheres, and fiberglass units operate satisfactorily over the entire range of available moisture. A combination of fiber glass and plaster of paris provides sensitivity in both the wet and dry range and provides good contact between the soil and the unit.

Electrical-resistance instruments are sensitive to salts in the soil; fiberglass units are more sensitive than plaster of paris. Their readings are also affected by concentrations of fertilizer. Where fertilizer is spread in bands, the unit should be placed well to one side of the bands. Temperature also affects reading in all units, but much less than other sources of variation. In some units, calibration drift has caused changes of as much as I atmosphere of tension in a single season. The magnitude of a change depends on the number of drying intervals and the number of days between each. Readings also vary with soil type. Since the same reading may indicate different amounts of available moisture for different soil textures, the instrument must be calibrated for the soil in which it is to used. For good accuracy, each instrument site shall be calibrated. Due to the possibility of calibration drift, particularly if fertilizer is applied with irrigation, the calibration should be checked once or twice each growing season. Calibration should be done with an accurate method, such as the gravimetric or the chemical drying methods.

If readings are to be representative of an area, the blocks must be properly installed. Individual blocks must be placed in a hole, which disturbs the soil. If the soil is not replaced in the hole at the same density and in the same way as in the rest of the profile, the root-development and moisture pattern may not be representative. A good method is to force the block into undisturbed soil along the sides of the hole dug for placement of the blocks. In one type, the blocks are cast in a tapered stake. A tapered hole, the same size as the stake, is bored into the ground with a special auger. The stake is saturated with water and then pushed into the hole so that close contact is made between the stake and the soil.

Most of the commercial instruments give good indications of moisture content if they are used according to the manufacturer's instructions. For good results, however, the blocks need to be calibrated in the field for each job. Experience and careful interpretation of instrument readings are needed to get a good estimate of soil moisture conditions. Electrical conductivity sensors are becoming a popular tool, and are

Table NJ 9.5 Interpretations of readings on typical electrical resistance meter

Soil water condition	Meter readings [1/] (0—200 scale)	Interpretation
Nearly saturated	180 — 200	Near saturated soil often occurs for a few hours following an irrigation. Danger of water logged soils, a high water table, or poor soil aeration if readings persist for several days.
Field capacity	170 — 180	Excess water has mostly drained out. No need to irrigate. Any irrigation would move nutrients below irrigation depth (root zone).
Irrigation range	80 — 120	Usual range for starting irrigations. Soil aeration is assured in this range. Starting irrigations in this range generally ensures maintaining readily available soil water at all times.
Dry	<80	This is the stress range; however, crop may not be necessarily damaged or yield reduced. Some soil water is available for plant use, but is getting dangerously low.

1/ Indicative of soil-water condition where the block is located. Judgment should be used to correlate these readings to general crop conditions throughout the field. It should be noted, the more sites measured, the more area represented by the measurements.

recommended on finer textured soils with a high water holding capacity. These instruments are calibrated to read centibars of soil water tension correlated to tensiometer readings. Since they are actually measuring electrical conductivity which is converted to centibars of tension, they can operate in a much higher tension range resulting in more accurate readings. However in sandy soils they are not as sensitive as the tensiometer with a longer response time to soil moisture changes.

Diaelectric Constant Method:
The diaelectric constant of material is a measure of the capacity of a nonconducting material to transmit high frequency electromagnetic waves or pulses. The diaelectric constant of a dry soil is between 2 and 5. The diaelectric constant of water is 80 at frequency range of 30 MHz — 1 GHz. Relatively small changes in the quantity of free water in the soil have large effects on the electromagnetic properties of the soil-water media. Two approaches developed for measuring the diaelectric constant of the soil-water media (water content by volume) are time domain reflectometry (TDR) and frequency domain reflectometry (FDR).

For TDR technology used in measuring soil-water content, the device propagates a high frequency transverse electromagnetic wave along a cable attached to parallel conducting probes inserted into the soil. A TDR soil measurement system measures the average volumetric soil-water percentage along the length of a wave guide. Wave guides (parallel pair) must be carefully installed in the soil with complete soil contact along their entire length, and the guides must remain parallel. Minimum soil disturbance is required when inserting probes. This is difficult when using the device as a portable device. The device must be properly installed and calibrated. Differing soil texture, bulk density, and salinity do not appear to affect the diaelectric constant.

FDR approaches to measurement of soil-water content are also known as radio frequency (RF) capacitance technique. This technique actually measures soil capacitance. A pair of electrodes is inserted into the soil. The soil acts as the diaelectric completing a capacitance circuit, which is part of a feedback loop of a high frequency transistor oscillator. The soil capacitance is related to the diaelectric constant by the geometry of the electric field established around the electrodes. Changes in soil-water content cause a shift in frequency. University and ARS comparison tests have indicated that, as soil salinity increases, sensor moisture values were positively skewed, which suggests readings were wetter than actual condition. FDR devices commercially available include:
Portable hand-push probes—These probes allow rapid, easy, but only qualitative readings of soil-water content. Probe use is difficult in drier soil of any texture, soils with coarse fragments, or soils with hardpans. A pilot hole may need to be made using an auger. The probe provides an analog, color-coded dial gauge (for three soil types—sand, loam, and clay), or a digital readout. The volume of soil measured is relatively small (a cylinder 4 inches tall by 1 inch in diameter). Several sites in a field should be measured, and can be, because probes are rapid and easy to use. Proper soil/probe tip contact is essential for accurate and consistent readings.

Portable device that uses an access tube similar to a neutron gauge—The probe suspended on a cable is centered in an access tube at predetermined depths where the natural resonant frequency or frequency shift between the emitted and received frequency is measured by the probe. The standard access tube is 2-inch diameter schedule 40 PVC pipe. Installation of the access tube requires extreme care to ensure a snug fit between the tube and the surrounding soil. Air gaps or soil cracks between the tube and soil induce error.

The device is calibrated by the manufacturer to sand and to an average bulk density for sand. Recalibration is required for any other soil texture and differing bulk density. The volume of soil measured is not texture or water content dependent, and approximates a cylinder 4 inches tall and 10 inches in diameter. Accuracy can be good in some soils with proper installation and calibration, and there are no radioactive hazards to personnel such as when using a neutron gauge. Proper installation of the access tube is essential and can be quite time consuming. Accuracy of data is largely dependent on having a tight, complete contact between the access tube and the surrounding soil. Before making a large investment in equipment, it is highly recommended that adequate research be done on comparison evaluations that are in process by various universities and the ARS. Good sources of information are technical papers and proceedings of ASAE, ASCE, and Soil Science Society of America, as well as direct discussion with personnel doing evaluations.

Other electronic sensors—Numerous sensors are commercially available using microelectronics. Inexpensive devices sold at flower and garden shops measure the electrical voltage generated when two dissimilar metals incorporated into the tip are placed in an electrolyte solution; i.e., the soil water. Most of these devices are sensitive to salt content in the soil-water solution.

Factors to be evaluated for the selection and application of a soil-water content measuring program include:

- Initial cost of device, appurtenances, special tools, and training
- Irrigation decisionmaker’s skill, personal interest, and labor availability

- Field site setup, ease of use and technical skill requirements
- Repeatable readings and calibration requirement
- Interpretations of readings—qualitative and quantitative needs
- Accuracy desired and accuracy of device
- Operation and maintenance costs
- Special considerations including licensing from NRC (private individuals do not operate under ARS licensing), storage, handling, film badge use, training required, disposal of radioactive devices, and special tools required for access tube installation.

(d) Irrigation Scheduling

The determination of when and how much to apply requires a knowledge of the available water capacity (AWC) of the soil, the management allowed depletion (MAD) or plant stress level for the specified crop, the crop peak consumptive use, crop rooting depth, and the critical periods in the growing season when the crop should not be stressed.

Most crops should be irrigated before more than half of the available moisture in the crop root zone has been used. Some crops, however, are thought to do better at higher moisture levels (less moisture deficiency at time of irrigation). See Chapter 3, Crops. Generally, however, the need for irrigation is doubtful until the moisture deficit approaches one-third of the AWC of the crop root zone.

Irrigation must begin in time so that the entire irrigated area can be covered before the available moisture level in the last portion of the field to be irrigated reaches a point to cause unfavorable moisture stress of the crop. This aspect of management is crucial for systems that may need several days to irrigate the entire field area. Examples of such systems may be traveling gun systems, hand move lateral systems, and traveling lateral systems. One of the most effective ways of determining when and how much water to apply is to measure or estimate the soil water content as discussed previously. Measurements should be made in that part of the soil from which plant roots extract their moisture and according to the moisture-extraction pattern of the particular crop. There are other methods being developed to determine when to irrigate, but measuring soil moisture is the most effective method in use now.

Measurements should be taken weekly in spring and fall and more frequently during the hot weather and critical growth periods of the crop. The irrigator may be able to reduce the frequency of readings after he or she has become familiar with the pattern of moisture depletion. To accurately predict moisture levels, measurements should be taken and recorded regularly, regardless of the time of year or the stage of crop growth. Comparison of yearly records with crop yields helps the irrigator to improve his or her management of the irrigation system.

Irrigation Scheduling Methods

In New Jersey the following methods are used to schedule when and how much water to apply. These include: soil and crop monitoring methods; the checkbook method; and computer assisted methods. Growers are recommended to use either of these methods depending on their management preference.

Soil moisture content should be monitored to determine if an irrigation is needed based on predetermined critical levels for certain crops. The crop stress index method measures plant condition and compares that status to a well known reference for a well watered plant condition. Soil moisture monitoring before, during, and after the crop growing season is perhaps the most accurate irrigation scheduling tool.

Monitoring actual soil moisture is like receiving your bank statement from the bank, it affirms or cautions you when an error may exist or other adjustments may be needed. It is used together with the Checkbook Method of irrigation scheduling. This method has proven very useful for scheduling irrigations by providing a running account of available moisture in the effective root zone. Similar to bank account records of deposits (irrigation and rainfall) and withdrawals (evapotranspiration), the account balance provides the irrigator with information as to when to irrigate and how much water to apply. The method requires a daily recording of rainfall, estimated consumptive use, net irrigation amounts, and moisture balance throughout the growing season of the irrigated crop.

With internet access, growers can enroll in the South Jersey RC&D Weather Station Network which offers computerized irrigation scheduling using real time climate data to compute daily crop evapotranspiration. Using this service, the computer facilitates irrigation water management data as well as record keeping on the farm. (computer assisted checkbook method).

Irrigation scheduling utilizes two important principles:

1. When an adequate supply of available moisture is present in the effective root zone, the rate of consumptive use by a given crop depends primarily on. the stage of growth and climatological conditions.

2. When the moisture content of the effective root zone is known at any given time, the moisture content at any later time can be computed by crediting moisture gained from effective rainfall or irrigation and subtracting the daily moisture withdrawals during the elapsed time.

To apply the above principles, the following requirements are essential:

(1) Soil with good internal and surface drainage.

(2) An adequate irrigation system and water supply.

(3) Daily consumptive use values for the crop.

(4) Accurate total available moisture values.

(5) Determination of the effective root zone of the crop.

(6) Measurements of effective rainfall and irrigation applications at the site.

(7) Available soil moisture maintained above the lower limit of withdrawal (25 to 30 percent of the total available moisture.) It is desirable to make periodic soil moisture checks to determine actual available moisture.

Equipment Required:

(1) Wedge-shaped plastic rain gage, 2- by 2-1/2 inch minimum top opening.

(2) Record book

(3) Means of measuring average application rate of irrigation emission devices.

Rain Gauge Installation: To obtain a measurement of the rainfall in the irrigated area, the rain gauge should be set on a post located in field or in an open area adjacent to the field being irrigated. Its distance from nearby obstructions that might affect the catch, such as trees or buildings, should.be at least twice the height of the controlling obstruction. The gauge should be 3 to 4 feet above ground level with its top at least 3 inches above the top of the post.
The amount of rainfall in the gauge should be read at the lowest point of the water surface (meniscus). The reading should be made as accurately as possible, preferably to the nearest one-hundredth of an inch. After the rainfall amount has been recorded, the gauge should be emptied and reset in its holder.

Use of the Moisture Balance Sheet for Scheduling Irrigation:
Record all available pertinent information in the heading.

1. Determine the total available moisture-holding capacity of the effective root zone and record it in the heading of the form. Use the value given in Chapter 2, Soils, NJIG.

2. Determine the balance when irrigation is to begin, (MAD). The value frequently used is 50 percent of AWC.

Recording Procedure:

1. On a date near the normal planting date, or start of growth for forage crops and tree fruits, when the field is at field capacity, enter the total available moisture-holding capacity of the soil in the soil water content column on the Scheduling Worksheet.

- When the soil moisture content is below field capacity at the time the moisture balance sheet is started, the available moisture remaining at that time will have to be estimated or measured. If the moisture percentage at field capacity has been previously determined for the field, measurement of present moisture percentage is all that is needed to provide an accurate starting value.
- If field measurement of moisture percentage at field capacity has not been possible, begin the account with an estimated value. At the first opportunity after adequate rain or irrigation, obtain the field capacity moisture percentage and correct the account accordingly.
- If at the time of plant emergence, a week or more has passed since the soil was at field capacity, and land preparation and seeding operations have ensued, the moisture balance may be estimated as being about 0. 5 inch below the field capacity value.
- Early season moisture losses prior to plant emergence may be estimated by using an evaporation rate from the soil surface of 0.03 inch per day for the first week after the soil has been wetted to field capacity. An evaporation rate of 0.03 inch per week may be used for the remaining period. For bare or tilled soil conditions during May or later season plantings, when the mean daily temperature is above 63 degrees F, evaporation from the top 6 inches of soil may be estimated to average 0.1 inch per day for the first 5 days, and 0.05 inch per week thereafter.

- Moisture losses may be estimated by measuring the depth of the dried surface layer and multiplying this depth by the available waterholding capacity of the soil per inch of depth.
- When a sod or cover crop is plowed under shortly before the planting date, the moisture balance may be considerably less than field capacity. Unless total rainfall between plowing and planting has brought the moisture level to field capacity or above, the moisture content of the soil should be measured at the start of record keeping.

2. At the end of the first day of moisture accounting:
   - Estimate crop consumptive use, ETc: Real time weather data from SJRC&D Weather Station Network which calculates ETc; Irrigation Water Requirements Software Program (uses historical weather data and crop coefficients) or evapotranspiration tables for North, South, and Central NJ (Tables NJ 4.2).
   - Record the amount of rainfall or the net amount of irrigation applied. Amounts should be recorded to nearest 0.01 inch.
   - Starting with the preceding day's balance, subtract the Et use value. If there has been rainfall exceeding 0.2 inch, or irrigation, add these values to the daily moisture balance to obtain the new daily balance. If the total exceeds the value for Available Moisture at field capacity in the root zone, enter the Available Moisture recorded in the heading of the form. If the total exceeds the Available Moisture value at field capacity by 0.5 inch or more, continue the full moisture balance value for two succeeding days. During this 2-day period the plants will be using the free water in the root zone.

3. Continue the same process as outlined above at the end of each day during the growing season until the crop has reached the desired maturity level.

Month ______________ Field ______________

Soil Texture Loam Available water 1.6 inches

Allowable Depletion 0.4 inches (25%)

Irrigate At 30 CB Irrigation Rate of Application 0.078 "/hr (net)

Date	Site #1 Sensor Readings (CB)		Site #2 Sensor Readings (CB)		Rainfall (inches)	Run Time (hours)	Irrigation (inches)	ET (inches)	Moisture Balance	Fertigation (hours)
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
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26										
27										
28										
29										
30										
31										

Total For Month: ET ______________ Rainfall ______________ Irrigation ______________

Weather Station- ______________

When the daily moisture balance is allowed to drop below 50 percent of the total available moisture value, soil moisture tensions will increase to the point where it becomes increasingly difficult for the plants to obtain the moisture they need for continuous vigorous growth. In such cases, daily evapotranspiration will be reduced.

If for some reason irrigation is not accomplished when the daily moisture balance has reached the 50 percent level, Et values must be reduced. The actual reduction in Et rates varies with the kind of crop and is difficult to define; however, the following factors can be used as a guide for estimating probable daily Et rates:

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

The net application is determined by (1) obtaining the difference between the recorded daily balance prior to the start of irrigation and the available moisture at field capacity in the root zone; (2) adding to this value the estimated Et for that day; and (3) making proper allowance for any effective rainfall that may have occurred since recording the last daily balance. The gross application is determined by dividing the net application amount by the expected efficiency of the irrigation method used on the particular field.

Variations in the procedure may be used to fit individual situations.

The time required to apply the required gross application is determined by dividing the gross application amount by the application rate of the irrigation system as determined from an on-site evaluation of the irrigation system.

Location of Soil-Moisture Devices

The selection of soil moisture measurement stations is important. The stations should be located so that average soil moisture conditions in the root zone of the crop are measured. Excess water from leaks in pipe joints, low spots in a field, etc., should not be allowed to come in contact with the measurement station. High spots with excessive water runoff should not be chosen because the soil profile in this area will not represent average root zone conditions. Average soil and slope conditions in the field should be represented in station locations. Measurements should be made at other locations as indicated by any critical condition in the soil, such as an area that dries out first. It is a good practice to have at least two measurement stations in each critical area and two or three stations in areas that are typical of the field. This information provides direction for adjusting the amount and frequency of irrigation for different parts of the field or for different periods in the growing season.

Measurement Depth:

(1) In uniformly textured soils, one measurement should be made at the midpoint in each quarter of the root zone. For shallow rooted crops (maximum 3 foot deep root zones), it is probably desirable to take three measurements. As an example, in a 24-inch root zone, measurements may be taken from the 6-, 12-, and 18-inch depths.

(2) In stratified soils, one measurement should be taken from each textural strata. It may not be necessary to take a measurement in very thin layers when this thin layer can be

lumped with another layer for estimating soil moisture. Where the strata is thick, a sample should be taken in 1-foot increments as a minimum. Thickness of the strata should be noted.

(3) The crop root depth for annual crops changes through the early part of the growing season. Measurements should be made in the soil profile according to the current depth of the majority of the crop roots.

Location in Relation to Plants: For row crops, locate the measurement in the crop row as near the plants as possible. For complete cover crops, such as alfalfa and small grains, locate in representative soil and slope areas of the field. For trees, locate about 4 to 6 feet from the trunk, but inside the tree drip line.

Location in Relation to Irrigation Systems:

(1) Lateral move (side roll or hand move) sprinklers-locate measurement stations halfway between adjacent sprinkler heads and 10 to 15 feet from the lateral.

(2) Center pivot sprinklers - locate measurement stations at about two-thirds of the total lateral distance from the pivot.

(3) Solid set sprinklers - locate measurement stations where the diagonals from four adjacent sprinkler head cross.

(4) Trickle systems - locate in the wetted ball in the root zone.

(5) Furrows and corrugations - measurement stations should be located in about the center of the furrow or corrugation bed near the plants.

Location in Field for Sprinkler or Trickle Irrigation System: Sprinkler and trickle irrigation systems lose pressure down the lateral due to friction loss throughout the lateral, so sprinkler heads farthest from the main lines put out the least irrigation. Locate measurement stations as follows:

(1) 50 to 100 feet downstream from the beginning of the lateral.
(2) 50 to 100 feet upstream from the distal end of the lateral.
(3) At least one measurement close to the center of the lateral. For laterals 1,320 feet to 2,640 feet long, locate two measurement stations at the one. For shorter laterals, one center third points along the lateral measurement should be adequate.

(e) IRRIGATION SYSTEM EVALUATIONS

The performance of an irrigation system can be determined by making field observations and evaluations. These observations can be used to determine average net water applications, uniformity, and efficiency. The results can be used to improve the irrigation system and water management techniques. These improvements should save money by conserving water and energy, reducing nutrient loss and improving crop yields. Simple evaluation techniques are presented in this chapter for sprinkler and trickle irrigation systems. For more complete evaluations and for other irrigation systems, refer to the National Engineering Handbook, Section 15, Irrigation, Chapter 3, National Irrigation Guide, Chapter 9, and Farm Irrigation System Evaluation: A Guide for Management.

Irrigation Efficiency Definitions

Irrigation efficiencies are a measure of how well an irrigation system works as well as the level of management of the system. Refer to the National Irrigation Guide page 9-31 – 9-32 for definitions.

Sprinkler Irrigation Field Evaluation

Successful operation of sprinkle irrigation systems requires that the frequency and quantity of water application be accurately scheduled. Field application efficiency must be known to manage the quantity of application. Since system performance changes with time, periodic field checks are recommended. Since many sprinkler systems are moved from field to field, a measurement of application performance is essential for each layout.

Sprinkler Performance

Often it is desirable to check the performance and output of a specific sprinkler head. The pressure at a sprinkler is measured with a gauge equipped with a pitot tube. The pitot tube must be centered in the discharge jet, which must impinge directly onto the tube tip. The tip should be held about 1/8 inch from the sprinkler nozzle and rocked slightly. Record the highest pressure reading shown. To measure the actual output of a sprinkler, slip a short length of hose over the sprinkler nozzle and collect the flow in a container of known volume. The hose should fit loosely enough to prevent a syphoning action. Record how long it takes the container to fill. Repeat several times and compute the average. If the sprinkler has two nozzles, measure the outputs from each nozzle separately. Check nozzle erosion with a feeler gauge, such as a drill bit that has the diameter specified for the nozzle.

Application Rate and Amount:

An accurate determination of the average irrigation application is important in the Moisture Accounting Method. As a minimum, sufficient depth-of-application data needs to be obtained for the control area which is chosen for moisture accounting. The following procedures can be used to obtain the necessary data where application rate does not exceed intake rate and sprinkler patterns are not distorted by wind.

Place a minimum of two rows of sampling cans perpendicular to the lateral lines, one row located near the sprinkler and the other midway between sprinklers or individual sprinkler settings. The spacing between sampling cans should be no more than 10 percent of the lateral line spacing. The first can from the lateral line and the last can of each row should be placed at a distance equal to one-half of the regular spacing between cans. The row of cans at the sprinkler head should be located a distance of one-half space upstream or downstream from the sprinkler. For cases where only one lateral line of sprinklers or individual giant hydraulic type sprinkler is in operation at a time, the rows of sampling cans extend each way from the lateral line for a distance about equal to the lateral spacing.

See Figure NJ 9.5 for example arrangements of sampling cans.

The sampling cans should be straight sided with thin rims. Oil cans, fruit juice cans, coffee cans or similar may be used by cutting out the tops. The cans should be placed plumb and with the top rim a minimum of 4 inches above the vegetation.

Measurement of sprinkler application should be made when climatic conditions are normal. The layout of the sampling stations may be made prior to starting the sprinklers. When this is done, the sprinklers adjacent to the sampling area should be temporarily fixed so that jets are directed away from the sampling area. When the system has developed full pressure and normal jet characteristics, the sprinklers are released and the time is noted. For convenience in determining the application rate, the duration of the test should be I hour. After 1 hour's operation, the cans are removed from the sampling area for measurement. For convenience of measurement, the water in the cans for each row may be poured into one can and measured with a rule.

When two adjacent laterals are operating simultaneously (Figure 9.IA), the total application in inches is:

$$\frac{A + B}{2N} \quad \text{(eq. 9. 1)}$$

The application rate in inches per hour is:

$$\frac{A + B}{2NH} \quad \text{(eq. 9.2)}$$

Where:

A = total accumulation in row A
B = total accumulation in row B
N = total number of cans in rows A and B
H = number of hours of test

When only a single lateral or an individual sprinkler is operating (Figures 9.lB and 9.IC), the total application in inches is:

$$\frac{A_1 + A_2 + 2(B_1 + B_2)}{\frac{N}{2}} \quad \text{(eq. 9.3)}$$

and the application rate in inches per hour is:

$$\frac{A_1 + A_2 + 2(B_1 + B_2)}{\frac{N}{2}H} \quad \text{(eq. 9.4)}$$

Where:

A_1 and A_2 = total accumulation in rows A_1 and A_2

B_1 and B_2 = total accumulation in rows B_1 and B_2

N total number of cans in rows A_1, A_2, B_1, and B_2

The above method applies to rectangular, square.or triangular sprinkler spacings.

The average application rate may be determined by measuring the discharge in gallons per minute from individual sprinklers. The average application rate in inches per hour is determined by the formula:

$$\text{application rate} = \frac{(96.3)\ (\text{gpm})}{(\text{Sm})\ (\text{S1})} \quad \text{(eq. 9.5)}$$

Where:

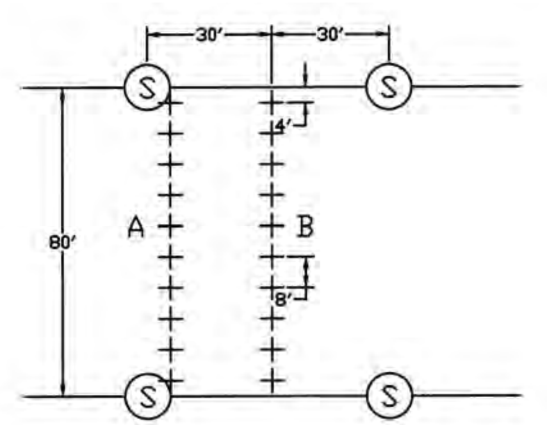
application rate is in inches per hour

gpm = measured discharge from sprinker in gallons per minute

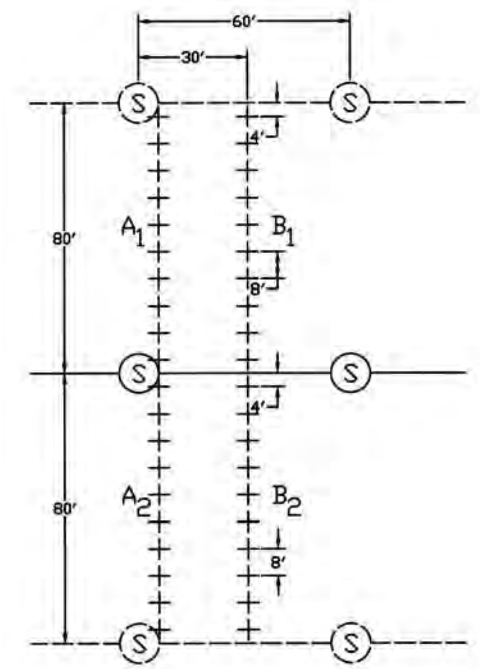
Sm = spacing of laterals along the main, in feet

S1 = spacing of sprinklers on the lateral, in feet

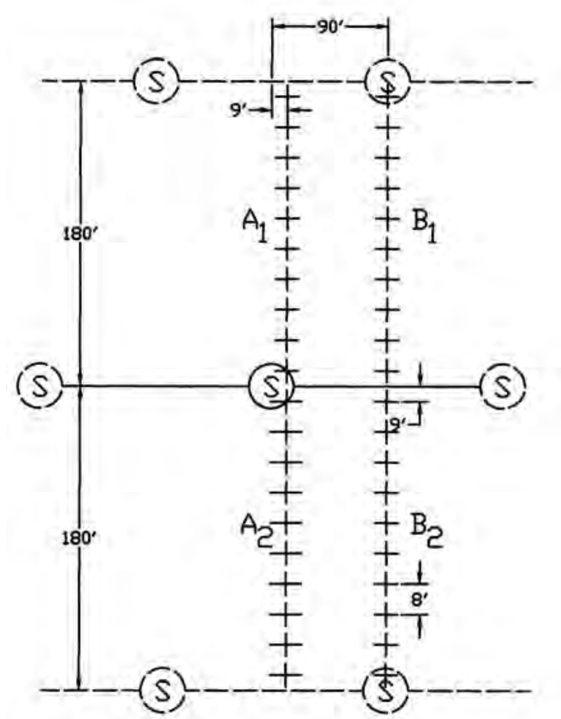
Figure NJ 9.5 Example Arrangements of Sampling Cans



Two adjacent laterals in operation
Sm = 80; S1 = 60
Figure NJ 9.5 A

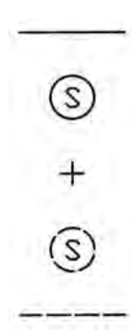


Single lateral operation
Sm = 80; S1=60
Figure NJ 9.5 B



Single sprinkler operation
Sm = 180; S1 = 180
Figure NJ 9.5 C

Symbols



Operating lateral

Operating sprinkler

Sampling can

Subsequent setting, sprinkler

Subsequent setting, lateral

A, B, A_1, A_2, B_1, B_2 — Rows of sampling cans

System Evaluation:
The following guidelines can be used when evaluating sprinkler systems operating in sets. Any recommendations as a result of an evaluation must be based on good judgment and consideration of all factors involved for the specific site, including, but not limited to, the irrigator's management style, crop needs, system type, and economics:

1. Loss in mainline should not exceed 30 percent of pump pressure. Higher losses in the mainline may indicate a poor design, or damage or degradation of the system. Due consideration must be given to pressure loss because of elevation change.

2. Pressure in lateral should not vary more than 10 percent from average pressure. This will assure a minimum application rate of at least 90 percent of maximum rate.

3. Spacing of nozzles along lateral should not be more than 50 percent of the wetted diameter. Spacing of laterals should not exceed 60 percent of wetted diameter. Wider spacings are very susceptible to non-uniform water distribution caused by wind.

4. The following rule-of-thumb may be used. The average sprinkler discharge can be computed as the discharge at the first nozzle less three-fourths the difference between the first and last nozzle.

5. When the time of set is near completion, the water applied by a nozzle should disappear from the surface by the time the nozzle makes a complete revolution. This indicates that all of the applied irrigation is absorbed by the soil and no runoff occurs.

Procedure:
Determine the following by field observation and review of design data:

1. The estimated net irrigation that is needed.
2. Spacing of sprinklers and laterals.
3. Size of sprinkler nozzles.
4. Size of main and lateral lines.
5. Size of field and predominant slope.
6. Elevation differences in the system, if significant.
7. Pressure at pump. Use a pressure gage.
8. Pressure at first and last nozzle. Use pitot tube gage.
9. Pressure at, and location of, high point of line, if significant. Use pitot tube gage.
10. Maximum length of main and lateral lines.
11. Location of line in relation to field boundaries.
12. Diameter of spray pattern.
13. If application rate is exceeding soil intake rate.

Example:

1. Soil: Adelphia, with predominant 2 percent field slope. Maximum allowed application rate = 0.5 inch/hour (Table NJ 2.1). Crop is corn. Net irrigation needed is estimated to be 2.0 inches (near 50% AWC depletion, Tables NJ 2.1, NJ 3.4). (Field check)

2. Spacing of laterals is 60 feet, and sprinklers are 40 feet apart on the lateral (field observation). There are 33 sprinklers per line.

3. The sprinkler nozzles are 13/64 x 5/32 (field check).

4. The main line is 7-inch and lateral lines are 4-inch diameter (field observation).

5. Field slope is 2%.

6. Elevation difference is relatively small, about 5 feet along the lateral.

7. Pressure at pump is 60 psi (pressure gauge).

8. Pressure at first nozzle is 45 psi, pressure at last nozzle, 1300 feet from main, is 28 psi. (Pressures were measured with pitot tube gauge.)

9. Pressure at high point, 580 feet from main, (15th nozzle) is 30 psi. (Pitot tube).

10. Maximum main length is 1290 feet, lateral lines are 1300 feet maximum length. Laterals branch off of central main line. Field checks made at 990 feet from pump.

11. Main line is located in middle of irrigated area, with laterals going to edge of field.

12. Diameter of spray pattern is 100 feet at last nozzle (field observation).

13. No water remains on surface by the time the nozzle makes a complete revolution. No runoff observed. (Field observation.)

Solution:

1. Discharge from first nozzle at 45 psi pressure is 8.1 + 4.7 = 12.8 gpm. (Table NJ 6.10)

2. Discharge at high point at 30 psi pressure is 6.5 + 3.9 = 10.4 gpm. (Table NJ 6.10)

3. Discharge at last nozzle at 28 psi pressure is 6.3 + 3.7 = 10.0 gpm. (Table NJ 6.10)

4. Average discharge to high point:

   12.8 - 3/4 (12.8 - 10.4) =11.0 gpm

   Average discharge, high point to end:

   10.4 - 3/4(10.4-10.0) = 10.1 gpm

   Average sprinkler line discharge:

   $$\frac{15(11.0) + 18(10.1)}{33} = 10.5 \text{ gpm.}$$

5. Pressure variance is 45 - 23 or 17 psi. The average pressure is

   $$\frac{45 + 28}{2} = 36.5 \text{ psi.}$$

   The pressure varies 8.5 psi each way from the average or a pressure variance of

   $$\frac{8.5}{36.5} = 23 \text{ percent from average.}$$

   (Pressure variance should not exceed $\pm$ 10 percent; therefore, lateral lines are too small, item 2, page 9.5)

6. Loss in 7" main line = 14 psi for 990' length. For 1,290' to last lateral connection, the equivalent loss would be

   $$\frac{1{,}290 \times 15}{990} = 19.5 \text{ psi.}$$

   Maximum main line loss should be approximately 30 percent of pump pressure (page 9.5, item 1). 30% of 60 psi = 18.0 psi; therefore, main line is slightly small for optimum design but this loss is only at maximum distance and would not justify purchasing larger pipe.

7. Spray pattern diameter – 100’ (observed). Lateral spacing should not exceed 60 percent of spray pattern or more than 60 feet. Therefore, lateral line spacing is satisfactory for 40’ x 60’ spacing.

8. Maximum application rate of 12.8 gpm on 40’ x 60’ spacing is approximately 0.5”/hr. Maximum allowable rate for corn is 0.5 inch/hour. (Table NJ 2.1)

9. Minimum application rate is 10.0 gpm (last nozzle). Maximum rate is 12.8 gpm (first nozzle). Minimum rate is, therefore,

   $\frac{10.0}{12.8}$ or 78% of maximum.

   Minimum rate should be at least 90 percent of maximum. There fore, pressure loss in lateral lines is excessive.

10. Design efficiency is 6 5 percent.

11. Minimum application rate of 10.0 gpm on 40’ x 60' spacing is 0.4"/hr. To apply 2 inches net application at 65 percent efficiency would require

   $\frac{2.0}{0.4 \times 0.65}$ = 7.7 hours.

12. No runoff was noted, so application rate does not exceed soil intake rate.

Recommendations:
For more uniform application, increase lateral lines to 5 inch diameter for first 600 feet of each lateral. Economic feasibility should be determined.

Plan to irrigate on 8-hour schedule.

Center-Pivot Evaluation

Procedure:
1. Determine operating pressure at pivot and gpm entering system.

2. Calculate rate of speed and time to make circuit of field.

3. Set spray catch cans as shown in sketches below, ahead of Sprinklers so one complete pass is made over cans. Set cans level and support above the vegetation. Catch cans should be calibrated so that volumetric measurements can be made. Quart oil cans are satisfactory and these hold approximately 200 cc per inch of depth. Therefore, 10 cc would be equivalent to 0.05 inch.

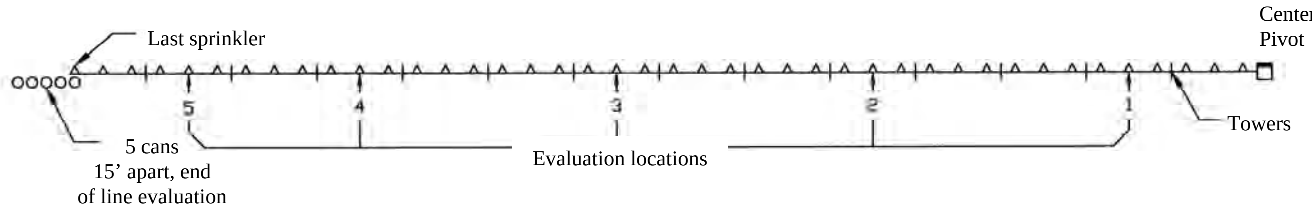
4. Observe the rate water enters the soil, particularly at the far end of the line. If there is appreciable runoff, erosion or ponding that will damage crops, the rate is too high. Record distance from pivot to point where runoff is evident.

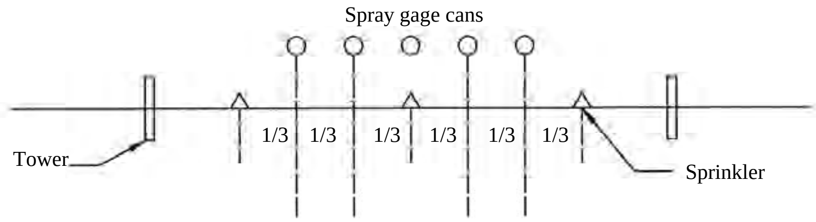
5. Determine if end gun operates on entire circle or at corners only.

6. After the discharge of the sprinklers is out of range of the cans, measure the water in each group of cans. Use a graduated cylinder that is divided into cc’s.

7. From can catch, determine:
   A. Uniformity of distribution.
   B. If applied amount will meet Peak periods use needs.

8. To make evaluation, use the following:
   A.100 gpm 0.221 acre-inch per hour
   B. Distance traveled is 6.28 times radius to drive wheel





Example:

1. Soils are Collington, with average field slope of 4 percent (from irrigation plan); maximum allowable application rate is 0.6 inch/hour (Table NJ 2.1). Field is square, 160 acres. 134 acres irrigated. (Irrigation plan).

2. Crop: Corn (field observation).

3. Operating pressure at pivot: 72#/sq. in. (Pressure gauge reading).

4. Water supplied by pump is 745 gpm (meter on system).

5. System length is 1300 feet total, 1250 feet radius to outside drive wheel (from system details).

6. Time for outside drive wheel to travel 100 feet is 85 minutes (field observation, timed).

7. Wetted diameter for sprinklers on outside sections is 100 feet (field observation).

8. End gun is used in corners only (observed).

9. Spray catch cans were set as shown in the sketch. After the system completely passed the cans, the samples were collected, recorded and averaged.

   Average catch in cans (quart oil cans were used, so 10 cc =0.05 inch):

   Group #I: 230 cc or 1.15 inches
   Group #2: 210 cc or 1.05 inches
   Group #3: 190 cc or 0.95 inches
   Group #4: 200 cc or 1.00 inches
   Group #5: 180 cc or 0.90 inches

   Cans at end of system:

   #1:200 cc or 1.00 inches
   #2:180 cc or 0.90 inches
   #3:140 cc or 0.70 inches
   #4: 90 cc or 0.45 inches
   #5: 40 cc or 0.20 inches

10. There was minor ponding observed at the outside drive wheel area, but no significant runoff was observed at any location.

Solution:

1. Rate of travel is

$$\frac{100'}{85 \text{ min.}} = 1.18 \text{ ft./min.}$$

2. Travel distance for 1,250 feet radius

   6.28 x 1,250 = 7,850 feet

3. Travel time for one complete circuit

$$\frac{7{,}850 \text{ feet}}{1.18 \text{ fpm} \times 60 \text{ min.}} = 111 \text{ hours or } 4.6 \text{ days}$$

4. Gross application: (note: 100 gpm = .0.221 acre inch/hour)

   Gross application

   $\frac{745 \text{ gpm}}{100}$ x 0.221 ac.in/hr x 111 hr. = 182.8 ac.in.

   A 1300 foot system covers an area of 134 acres with the gun sprinkler used in the corners only. Therefore, gross application = 182.8/134 = 1.36 inches.

5. Average catch for least catch area (except end gun) is 0.90 inch for Group #5. The travel time for one circuit is 4.6 days, so the system can supply 0.90/4.6 = 0.20 inches/day. The minimum design consumptive use rate is 0.20 inches per day for central New Jersey (pg 4-5).

6. Net application varies from 0.90 to 1.15 inches. Minimum is then 79 percent of maximum.

7. Average amount caught (net application) is 1.01 inches, or 74 percent of gross application.

8. There is no problem with runoff, so the application rate is satisfactory for this soil. Ponding at outer drive wheel area indicates application rate is near soil intake rate for the furthest out section.

Recommendation:
The irrigator should be careful to begin irrigating well before the AWC is depleted by 50 percent. The system has barely enough capacity to supply water at the consumptive use rate when operated full time, and the system takes 4.6 days to make a full circuit. This allows little margin for late starts or equipment breakdown. Application rate can not be significantly increased without causing runoff and erosion (#8 above).

<u>Micro Irrigation Field Evaluation</u>
Successful operation of micro irrigation requires that the frequency and quantity of water application be accurately scheduled. The field application emission uniformity, EU’, must be known in order to manage the quantity of application. Unfortunately, EU’often changes with time; therefore, periodic field checks of system performance are necessary.

The data needed for fully evaluating a trickle irrigation system are available by determining:

1. Duration, frequency, and sequence of operation of normal irrigation cycle.

2. The management allowed deficit (MAD) and the soil moisture deficit (SMD). The soil moisture deficit is the difference between field capacity and the actual soil moisture in the root zone at any given time.

3. Rate of discharge at the emission points and the pressure near several emitters spaced throughout the system.

4. Changes in rate of discharge from emitters after cleaning or other repair.

5. The percent of soil volume wetted.

6. Spacing and size of trees or other plants being irrigated.

7. Location of emission points relative to trees, vines, or other plants and uniformity of spacing of emission points.

8. Losses of pressure at the filters.

9. General topography.

Equipment Needed
The equipment needed for collecting the necessary field data is:

1. Pressure gauge (0-50 psi range) with 'IT" adapters for temporary installation at either end of the lateral hoses.

2. A stopwatch or watch with an easily visible second hand.

3. Graduated cylinder with 250 ml capacity.

4. Measuring tape 10 to 20 ft long.

5. Funnel with 3- to 6-in diameter.

6. Shovel and soil auger or probe.

7. Manufacturer's emitter performance charts showing the relationships between discharge and pressure plus recommended operating pressures and filter requirements.

8. Sheet metal or plastic trough 3 ft long for measuring the discharge from several outlets in a perforated hose simultaneously or the discharge from a 3-ft length of porous tubing. (A piece of I- or 2-in PVC pipe cut in half lengthwise makes a good trough.)

Field Procedure
The following field procedure is suitable for evaluating systems with individually manufactured emitters (or sprayers) and systems that use perforated or porous lateral hose.

1. Record field, soil, and crop characteristics.

2. From the operator, determine duration and frequency of operation, how SMD is determined, and MAD.

3. Determine pressures at the inlet and outlet of the filter, and determine integrity of filter if possible.

4. Determine and record emitter and lateral hose characteristics, including manufacturer, sizes, types, materials, rated capacity or discharge, etc. Record the system discharge rate, if the system is equipped with a water meter. Sketch the system layout and note the general topography, manifold in operation and manifold where the discharge test will be conducted. Try to select a manifold which appears to have the greatest head differential for evaluation.

5. Locate four emitter laterals along the manifold; one should be near the inlet and two near the "third" points, and the fourth near the outer end.

6. For laterals having individual emitters, measure the discharge at two adjacent emission points at each of four different tree or plant locations on each of the four selected test laterals. Collect the flow for a number of full minutes (1, 2, and 3, etc.) to obtain a volume between 100 and 250 ml for each emission point tested. To convert ml per minute to gallons per hour (gph), divide by 63. Compute the average discharge for each pair of emission points.

   These steps will produce eight pressure readings and 32 discharge volumes at 16 different plant locations for- individual emission points used in widespaced crops with two or more emission points per plant.

   For perforated hose or porous tubing, use the 3-ft trough and collect a discharge reading at each of the 16 locations described above. Since these are already averages from 2 or more outlets, only one reading is needed at each location.

   For relatively wide-spaced crops such as grapes where one single outlet emitter may serve one or more plants, collect a discharge reading at each of the 16 locations described above. Since the plants are only served by a single emission point, only one reading should be made at each location.

7. Measure and record the water pressures at the inlet and downstream ends of each lateral tested in step 6 under normal operation. On the inlet end, this may require disconnecting the lateral hose, installing the pressure gauge, and reconnecting the hose before reading the pressure. Some systems are equipped with tire valve stems at the inlet end and pressure can be read with the use of portable gauge. On the downstream end, the pressure can be read after connecting the pressure gauge the simplest way possible.
8. Check the percentage of the soil that is wetted at one of the tree or plant locations

on each test lateral and record. It is best to select a tree or plant at a different relative location on each lateral. Use the probe, soil auger, or shovel -whichever seems to work best - for estimating the area of the wetted zone in a horizontal plane about 6 to 12 inches below the soil surface around each plant. Determine the percentage wetted by dividing the wetted area by the total surface area represented by the plant.

9. If an interval of several days between irrigations is being used, check the soil moisture deficit in the wetted volume near a few representative plants in the next area to be irrigated and record it. This is difficult and requires averaging samples taken from several positions around each plant.

10. Determine the minimum lateral inlet pressure, MLIP, along each of the operating manifolds and record. For level or uphill manifolds, the MLIP will be at the far end of the manifold. For downhill manifolds, it is often about two-thirds down the manifold. For manifolds on undulating terrain, it is usually on a knoll or high point. When evaluating a system with two or more operating stations, the MLIP on each manifold should be determined. This will require cycling the system. Compute the system average MLIP.

11. Determine the discharge correction factor, DCF, to adjust the average emission point discharges for the tested manifold. This adjustment is needed only if the tested manifold happened to be operating with a higher or lower MLIP than the system average MLIP. If the emitter discharge exponent, x, is known, use equation 9.6. Otherwise use equation 9.7.

$$DCF = \left(\frac{\text{average MLIP}}{\text{test MLIP}}\right)^x \qquad \text{(eq. 9.6)}$$

$$DCF = \frac{2.5 \times (\text{average MLIP})}{(\text{average MLIP}) + 1.5 \times (\text{test MLIP})} \qquad \text{(eq. 9.7)}$$

12. Determine the average and adjusted average emission point discharges according to equations 9.8 - 9.11.

Test manifold emission point discharges:

$$\text{Test manifold average} = \frac{\text{(sum of all averages)}}{\text{(number of averages)}} \qquad \text{(eq. 9.8)}$$

$$\text{Manifold low 1/4 average} = \frac{\text{(sum of low 1/4 averages)}}{\text{(number of low 1/4 averages)}} \qquad \text{(eq. 9.9)}$$

Where the "averages" are the average discharges of the emitter pairs computed in Step 6. The "low 1/4 averages" are the average discharges of the lowest 25% of the emitter pair discharges.

Adjusted average emission point discharges for system:

$$q_a = \text{System average discharge} = (DCF) \times (\text{Test Manifold Average}) \qquad \text{(eq. 9.10)}$$

$$q_n = \text{System low 1/4 average} = (DCF) \times (\text{Manifold Low 1/4 Average}) \qquad \text{(eq. 9.11)}$$

Utilization of field data

In trickle irrigation, all the system flow is delivered to individual trees, vines, shrubs, or other plants. Essentially, there is no opportunity for loss of water except at the tree or plant locations. Therefore, uniformity of emission is of primary concern, assuming the crop is uniform. Locations of individual emission points, or the tree locations when several emitters are closely spaced, can be thought of in much the same manner as the container positions in tests of sprinkler performance.

Average application depth. The average depth applied per irrigation to the wetted area, D_{aw}, is useful for estimating MAD.

$$D_{aw} = \frac{1.604\, e_n\, q_a T_a}{A_w} \qquad \text{(eq. 9.12)}$$

where:

D_{aw} is the average depth applied per irrigation to the wetted area (in.)
e_n is the number of emission points per tree or plant.
q_a is the adjusted average emission point discharge of the system from equation 9.10.
T_a is the application time per irrigation (hrs).
A_w is area wetted per tree or plant from Step 8 above, (ft2).

The average depth applied per irrigation to the total cropped area can be found by substituting the plant spacing, Sp X Sr, for the wetted area, Aw, in eq. 9.12.

Therefore:

$$D_a = \frac{1.604\ e_n\ q_a\ T_a}{S_p \times S_r} \quad \text{(eq. 9.13)}$$

in which:

D_a is the average depth applied per irrigation to the total cropped area (in)

S_p and S_r are plant and row spacing, ft.

Volume per day. The average volume of water applied per day for each tree or plant is:

$$G = \frac{e_n\ q_a\ T_a}{F_i} \quad \text{(eq. 9.14)}$$

in which

G is the average volume of water applied per plant per day (gal/day)

Fi is the irrigation interval (days)

Emission Uniformity. The actual field emission uniformity, EU’, is needed to determine the system operating efficiency and for estimating gross water application requirements. The EU’ is a function of the emission uniformity in the tested area and the pressure variations throughout the entire system. Where the emitter discharge test data is from the area served by a single manifold:

$$EU'm = \frac{100\ q_n}{q_a} \quad \text{(eq. 9.15)}$$

in which EU'm is the field emission uniformity (percent) of the manifold area tested and q_a and q_n are from equations 9.10 and 9.11.

Some trickle irrigations systems are fitted with pressure compensating emitters or have pressure or flow regulation at the inlet to each lateral. Some systems are only provided with a means for pressure control or regulation at the inlets to the manifolds, others are provided with regulators at each lateral. If the manifold inlet pressures vary more than a few percent (due to design and/or management), the overall EU' (of the system) will be lower than EU'm (of the tested manifold). An estimate of this efficiency reduction factor (ERF) can be computed from the minimum lateral inlet pressure along each manifold throughout the system by:

$$ERF = \frac{\text{average MLIP} + (1.5\ (\text{minimum MLIP}))}{2.5\ (\text{average MLIP})} \quad \text{(eq. 9.16)}$$

in which

ERF is the efficiency reduction factor

MLIP is the minimum lateral inlet pressure along a manifold (psi)

Average MLIP is the average of the individual IMLIP along each manifold (psi)

Minimum MLIP is the lowest lateral inlet pressure in the system (psi)

A more precise method for estimating the ERF can be made by:

$$ERF = ((\text{minimum MLIP})/(\text{average MLIP}))^x \quad \text{(eq. 9.17)}$$

where x is the emitter discharge exponent.

The ERF is approximately equal to the ratio between the average emission point discharge in the area served by the manifold with the minimum MLIP and the average emission point discharge for the system. Therefore, the system EUI can be approximated by:

$$EU' = ERF \times EU'm \qquad \text{(eq. 9.18)}$$

General criteria for EUI values for systems which have been in operation for one or more seasons are: greater than 90%, excellent; between 80% and 90%, good; 70 to 80%, fair; and less than 70%, poor.

Gross application.required.. Since trickle irrigation wets only a small portion of the soil volume, the SMD must be replaced frequently. It is always difficult to estimate SMD because some regions of the wetted portion of 'the root zone often remain near field capacity even when the interval between irrigation is several days. For this reason, SMD must be estimated from weather data or information derived from evaporation devices. Such estimates are subject to error and, since there is no practical way to check for slight underirrigation, some margin for safety should be allowed. As a general rule, the minimum gross depth of application, I_g , should be equal to (or slightly greater than) the values obtained by eq. 9.19.

$$I_g = \frac{I_n \times T_r}{EU'/100} \qquad \text{(eq. 9.19)}$$

in which

I_g is the gross depth per irrigation, inches

T_r is the peak use period transpiration ratio

EU' is the emission uniformity, percentage

I_n is the net depth to be applied per irrigation, inches.

The Tr is the ratio of the depth of water applied (total needed) to the depth of water transpired during the peak use period. It represents the extra water which must be applied, even during peak use period, to offset unavoidable deep percolation losses. These losses are due to excess vertical water movement below the active root zone which is unavoidable in porous and shallow soils when sufficient lateral wetting is achieved. With efficient irrigation scheduling and for design purposes, use the following peak use period T_r values:

I. T_r = 1.00 for deep (greater than 5 ft) rooted crops on all soils except very porous gravely soils; medium (2.5 to 5 ft) rooted crops on fine and medium textured soils; and shallow rooted (less than 2.5 ft) on fine textured soils.

II. T_r = 1.05 for deep rooted crops on gravely soils; medium rooted crops on coarse textured (sandy) soils; and shallow rooted crops on medium textured soils.

III. T_r = 1.10 for medium rooted crops on gravely soils; or shallow rooted crops on coarse textured soils.

Simplified Irrigation System and Water Management Evaluation

Some simple evaluation items can be done by irrigation system operators that will help them make management and operation of irrigation equipment decisions. They include:

Item 1-For sprinkler and micro irrigation system, they can check:

- Operating pressures at pump, mainline, sprinkler heads, upstream and downstream of filters to assure they match design.
- Application depth for the irrigation set by using a few 3- to 4-inch random placed, straight sided, vegetable or fruit tin containers for catch containers. Measure water depth in catch containers with a pocket tape. Does it match design and what is desired?
- Discharge from a few microsystem emitters using a one-quart container and a watch. Do not raise emitter more than a few inches. Compute flow in gallons per hour. Do flows match design?
- Translocation and runoff from sprinkler systems.

Item 2-For all irrigation systems, simplified field checking by the operator can include calculation of depth of irrigation for a set using the basic equation,

$$QT = DA.$$

where:
Q = flow rate (ft^3/S)
T = time of irrigation application (hr)
D = gross depth of water applied (in)
A = area irrigated (acres)

Item 3-Using a probe, shovel, soils auger, or push type core sampler, the operator can put down a few holes after an irrigation to determine depth of water penetration. Does it match plant rooting depths? Depending on the irrigation system and soil, checking on water penetration could be anywhere from an hour after the irrigation to the next day.

Item 4-Check runoff. Is it excessive? Does it contain sediment?

Abbreviated Water Management and Irrigation System Evaluations

An abbreviated evaluation can determine whether a problem exists in a field and how serious it may be. Such an evaluation should always precede a more detailed evaluation. With some guidance the irrigation decision maker can perform abbreviated system evaluations themselves. Many times, needed changes can be identified in less than an hour. Refer to National Irrigation Guide, Chapter 9.

Chapter 10

Conservation Management Systems and Irrigation Planning

Contents **NJ652.10**

NJ652.10 Conservation Management Systems and Irrigation Planning

(a) General

Irrigation system planning must consider the potential interactive effect on soil, water, air, plants, and animal resources (SWAPA), plus how an action my affect the onsite and offsite human environment. **An irrigation water management plan is a component of an overall farm conservation plan.** Refer to the National Irrigation Guide, Chapter 10 page 10-2, for more detailed objectives of an irrigation plan and the planning process.

(b) The Planning Process

The first phase of irrigation planning is to conduct a resource inventory, and analyze data. An inventory and evaluation is conducted to collect resource data. Some of the more important data required for planning are soils, crops, topography, water supply, existing physical features, existing irrigation systems, water table presence, existing drainage systems, environmental factors, present farm operation, skill and labor available, operators desires and concerns, and energy resources. Refer to Irrigation Site Evaluation Form and General Planning Worksheet.

Soils: The soil survey is a prime source for soils information. In addition a field investigation is generally necessary to identify actual surface soil texture, plant root zone volume, and compaction. Compaction can limit plant root development and water measurement. Judgment must be used by the planner in determining how reliable existing data are and if additional detail surveying an testing are needed.

Crops: Identify crops grown and determine peak crop evapotranspiration rate. Determine net irrigation water requirements and frequency of irrigation based on soils and crops grown. Find out cultural practices used. This includes cultivation sequence, equipment used, width of equipment, crop varieties, fertilizer usage and time of application, crop rotations, and planting and harvest dates. Discuss crops and cultural practices used in a planned cropping sequence.

Topography: Determine high and low points in the field and direction of irrigation. A detailed topographic map is often necessary for planning and designing micro and low pressure sprinkler irrigation systems. Small changes in elevation can have large effects on irrigation uniformity when using low pressure irrigation systems.

Water Supply: Determine flow rate, source location and elevation of water supply. Water quality, including chemical content, sediment, and debris loads also need to be determined. Quality of runoff water from upstream can determine its suitability for use on certain crops. Runoff water may contain certain pesticides and their metabolites, nutrients (phosphorous) and sediment. Tailwater Recovery and reuse should be considered where allowed by local water regulations. It may be necessary to obtain laboratory tests for chemical content, measure water supply flow rates, and treat tailwater through chlorination or ionization processes. Such practices are being implemented on container nursery operations in New Jersey where runoff from sprinkler systems in hoophouses are collected and reused.

Existing Physical Features: Determine access to all parts of the irrigated area and location of roads, above ground utilities, buried utilities, and other physical features. Depth to buried utilities may control excavation location and depths. Above ground utilities may limit the use and layout of sprinkler systems (pivot and linear move, travelers). Use aerial photographs and maps as plan base maps and add sketches or overlays.

Existing Irrigation Systems: An analysis of the existing irrigation system and management helps to determine if it is appropriate for the resources involved. Make an inventory of the existing system. Gather data on equipment brands, models, and capacities. Talk to the water user regarding their concerns about certain irrigation systems. Users deserve information on the best available method and systems that meet their needs and are most suitable for the site. To often the perception exists that to improve water application a new or different irrigation system must be installed. Using proper water management with the existing system often results in increasing water application efficiency more then 30 percent.

Water Table: Determine if there is a seasonal high water table that may contribute to either part or all of the crop water needs. Note the depth, duration, drainage and water quality.

Existing Drainage Systems: Analyze existing surface and subsurface drainage facilities. Include condition of existing ditches and underground drains, sources of water and problems created by poor drainage.

Environmental Factors: Assess resources within the planning area. This can be facilitated using the environmental for resource management planning (Exhibit 5, Part 600.7, NRCS National Procedures Handbook).

Energy Resources: Inventory the existing power equipment or the availability and costs of proposed power sources. Diesel and gasoline engines for powering pumps can be more cost effective then electric. Estimate pump efficiency and consider total pumping plant evaluations.

(c) Irrigation Water Management Plan

The Irrigation Water Management (IWM) Plan is a segment of the Farm Conservation Plan and includes data needed by the water user to implement, operate, maintain, and properly manage the selected irrigation system. Components of the IWM Plan are grouped together in the IWM Notebook which is developed for the irrigator to use when implementing irrigation water management. IWM Notebook sections should include the following:

- **IWM Plan**: This includes details needed to manage the irrigation system. Items that should be included include: Soils information (intake and application rates); Operation details; Irrigation scheduling information; Design flow rates, gross and net depth of application; Installation and maintenance recommendations; and Water use log.
- **Irrigation Scheduling Checkbook Worksheets**
- **Design Material:** Site plan and system design worksheets. Location maps, aerial photographs, and soil and topo maps.

- **System Evaluation Reports:** A basic or more detailed evaluation of the irrigation system performance is recommended. Pump operating pressures and pressures throughout the system need to be checked and recorded. Flow measurements and uniformity checks should also be recorded in this section of the plan. The need for adjustments should be fully explained to the water user during the planning process.
- **Information Data Sheets:** Manufacturer specification sheets, irrigation scheduling reference sheets, flowmeter and backflow prevention devices are some examples of literature to include in this section.

(d) Planning Aids

The following worksheets can be used for irrigation planning and documentation in New Jersey:

- Irrigation Site Evaluation Form and General Planning Worksheet.
- Excel Irrigation Design Review Worksheets: These include sheets for all methods and systems used in NJ.
- Irrigation Water Management Notebook, template plan

Chapter 11 Economic Evaluations

Contents **NJ652.11**

NJ 652.11 Economic Evaluations

Refer to the National Irrigation Guide and Handbook of Economics for Conservation, Natural Resources Conservation Service, April 1992, for material and training activities relating to the economics of irrigation.

The National Irrigation Guide, Chapter 11, discusses the economics of installing new irrigation systems and operating existing systems, cost-benefit analysis, maximizing net returns, water yield relationships, economic pipe sizing and pump cost evaluation.

Chapter 12 Energy Use and Conservation

Contents **NJ652.12**

NJ 652.12 Energy Use and Conservation

Energy cost for operating an irrigation pumping plant is a major concern to most irrigation decisionmakers. Many are taking a close look at their pumping installations to find ways to reduce operating costs. Where practical, many irrigators are converting systems of high pressure and volume to low pressure, low volume sprinkler and microirrigation systems. Properly designed, operated, and managed systems can provide high irrigation efficiencies, and pump operating efficiencies.

Although energy conservation is not a specific NRCS objective, it is a national objective assigned to other water conservation activities that are NRCS objectives. Finding ways to reduce energy consumption in conjunction with soil and water conservation measures can be a major selling point when recommending conservation measures. The NRCS, National Irrigation Guide, Chapter 12, provides detail discussions on pump energy requirements, energy sources, pump design considerations, pumping plant installations, pipeline efficiency, variable or adjustable frequency drives for electric motors, and other energy sources for pumping water (wind, water, solar, and air). Also refer to NEH part 623 (Section 15), Chapter 8, Irrigation Pumping Plants, and Nebraska Pumping Plant Performance Criteria.

NJ 652.12 Energy Use and Conservation

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Chapter 13 Quality of Water Supply

Contents **NJ652.13**

NJ 652.13 Quality of Water Supply

(a) General

Water quality is a major consideration when selecting an irrigation method. Adequate water quality data is essential in the selection process. Water suitability for irrigation is determined by the potential to cause soil, plant, or management problems. Appropriate management practices should be selected to avoid unacceptable levels of biomass or yield reduction. Suitability must be evaluated at the farm level for specific use and potential hazard to crops and personal health. If contaminants are present, the type and concentration must be determined.

Undesirable contaminants in irrigation water can include the following: dissolved salts, suspended sediment, gypsum, toxic elements, nematodes, and water born diseases. Tailwater runoff from irrigation systems (particularly container nursery operations in hoophouses), can be reused as a water supply, but can also contain contaminants such as sediment, fertilizers, pesticides, and organic material. Grey water from other sources such as treated municipal sewerage, industrial wastes, agricultural food processing, and wastes from confined livestock and fish feeding operations can also be used to supplement supplies. Caution must be taken when applying treated wastes to cropland.

These sources can contain pathogens, viruses, coliforms, salts, toxic metals, or acids.

Refer to the NRCS National Irrigation Guide, Chapter 13, for detailed discussion on water quality effects as it relates to salinity and sodicity, infiltration and permeability, toxicity, suspended sediment, and wastewater reuse. Also refer to NRCS National Engineering Handbook, Part 623, Chapter 2, Irrigation Water Requirements.

b) Water Quality

The irrigation water supply should be tested for the following: iron, sulfur, manganese, calcium, pH, sand, organic matter, algae, pesticides, contaminants from industrial effluents, disease organisms, and salts. Concentrations may be found in water from wells, rivers, streams, ponds, or tidal inlets or streams. If they are present in sufficient concentrations, the water may be unfit for irrigation use on some crops. Water containing salts is often referred to as "brackish." Saline water is another term which usually designates contamination by salts to some degree. Sodium is the element in salt or saline water that has the greatest effect on the crop and the soil in which it may accumulate in harmful quantity if not leached below the root zone by fresh, percolating rainwater. Where sodium salts are the major contaminant, the potential for crop damage from salt residues on crops can be reduced by night application.

Sulfur may be present in some seepage waters in amounts large enough to cause burning of the foliage and fruit and to corrode irrigation equipment. Iron precipitants are a common concern in New Jersey with both drip irrigation and sprinkler systems. Iron can be treated through oxidation and good filtration or ionization processes to keep it in solution.

The amount of any contaminant that can be tolerated in irrigation water depends on: (1) the kind of contaminant present, (2) the tolerance of the crops to be irrigated, (3) the texture and permeability (internal drainage) of the soil being irrigated, (4) the amount of contaminant already accumulated in the soil, and (5) the type of irrigation system used.

Water sources can vary considerably in quality depending on the season, demand, rainfall, etc. Water contaminants include both inorganic and organic materials. Physical contaminants include organic matter such as algae, bacteria, leaves, fish, etc., and organic matter such as silt and sand. Chemical contaminants are soluble and only become a problem when they precipitate as a solid particle or when they stimulate organic growth. For example, temperature or pH change may cause iron or sulfur precipitation to occur.

Irrigation water quality is important for three main reasons. First is the effect of poor water quality on the crop. Chapter 3 gives limits on the use of saline or brackish water for irrigation to minimize crop damage. When irrigating with waste water, the nutrient content, the content of salts, and the content of solids must be known and the irrigation system designed within these constraints. The second reason is excessive wear on the system components. Normally this would be excessive wear of pumps and sprinkler nozzles caused by sand in the irrigation water. The third reason is plugging of the systems. The smaller the openings in the system, the greater a concern plugging becomes, such as with microirrigation systems. Clogging in these systems may be due to algae, bacterial slime, precipitates, and sediment. In general, adequate filtration, line flushing, and chemical treatment are used to avoid clogging.

Algae

Algae can be found in almost all quiet surface waters. Sunlight and water high in nutrients encourage its growth. Algae even grows in water that stands in an emitter after the system is turned off. Once algae gets into a trickle line, it is almost impossible to remove. Screening to remove algae is not satisfactory since screens and filters cab be plugged very rapidly. It is best to prevent algae from forming in the first place. Alternately, algae should be killed and settled at the source before it enters the system.

If water is not exposed to sunlight, algae will not grow; so use of dark colored, opaque tanks, pipe, and emitters are recommended.

In ponds, minimize the formation of algae by decreasing the sediment and nutrient concentrations. Treatment with copper sulfate will prevent algae formation and control slime. However, do not apply chemical treatments to surface waters without first consulting the appropriate regulatory agencies.

Bacterial Slime

Certain bacteria can secrete a slime that can eventually plug emitters and small lines in a microirrigation system. Conditions that favor its development include low pH, but not below 4.5; low oxygen level; temperature above 46 degrees F; organic matter; dissolved ferrous (iron) concentrations of 0.2 to 1.0 ppm; and hydrogen sulfide in concentrations or 0.1 ppm or greater. Clogging is generally not a problem if there is no iron or sulfide in the water.

Extra tubing may be added in a trickle system at the end or along a lateral for checking slime buildup. A small piece of tubing may periodically be cut and inspected. The slime often has the same color as the tubing but will have a greasy feel.

The treatment for bacterial slime is disinfectant. The most common treatment is chlorination, either with sodium hypochlorite or calcium hypochlorite. For hard water, sodium hypochorite is preferred to reduce calcium carbonate precipitation in the lines. The hypochlorites are relatively safe and easy to handle by conventional injection methods, but are expensive when needed at higher injection rates. Gaseous chlorine is less expensive for use on large scale operations but is extremely dangerous, requires special equipment, and special handling by trained personnel. Injection of chlorine at the end of the irrigation cycle is sometimes called superchlorination. It can be just as effective as continuous chlorination since most bacterial slime develops during the off-cycle. The injection time should be long enough to fill all of the lines.

Particle Agglomeration

Particles near the 2 micron size tend to stick together (agglomerate) and rapidly clog lines and orifices. A chemical dispersant, such as hexametaphosphate, or a settling basin can help control the problem as will flushing the lines and using emitters that will pass large particles.

Suction on Steep Terrain

On steep terrain, when the zone valve is turned off, emission points at low elevations may drain the system quite rapidly and create a suction on emission points at the higher elevations. If the emission points are buried, or if the outlet is submerged in the small surface puddle that often forms, muddy water can be sucked back into the lateral. To avoid this problem, install outlets above the ground and above the puddle. If the emission points are buried, it will help to lay laterals on the contour at nearly the same elevation.

Pond Sediment

Runoff into ponds introduces sediment and agitates the water. Natural convection currents can keep fine silt and clay particles (1 to 25 microns) in suspension for some time. As a result, microirrigation systems using a pond as a water supply must be designed to handle occasional changes of fine suspended particles. Sand media filters that have automatic back-flush are typically used.

Because open basins accumulate floating debris, it is important to use a coarse screened floating intake located one to two feet below the water surface. The intake should be frequently inspected and cleaned.

Precipitates

Wells drilled through limestone may yield water high in calcium bicarbonates. If the temperature or pH of the water is raised above certain critical points, calcium carbonate precipitates and forms a scale that adheres to the inner wall of pipes. This buildup caused by hard water occurs slowly but can become severe in time. Hardness cannot be treated by filtering or flushing. Acid can be used for cleaning but will never completely remove scale from blocked lines and emitters.

Water in laterals placed on the ground or under plastic can become heated, especially under no-flow conditions. When the water is hard, the high temperature will cause carbonate precipitation. Burying laterals will help to avoid the temperature rise.

To test for calcium carbonate stir a teaspoon of household ammonia into a quart of the supply water in a glass container. Allow to sit overnight. Formation of an almost white, sparkling crystalline precipitate that can neither be disturbed by agitation or rinsing is an indication of calcium carbonate.

Precipitation can also occur when certain chemicals are mixed. For example, chlorine will cause iron in water to precipitate. Most phosphate fertilizers react with the calcium in hard water and form a precipitate.

If precipitating chemicals must be used, inject them 100 to 200 feet upstream from the filtration system. At least two elbows should be used in the section of pipe between the injector and filtration to create extra turbulence for complete mixing and to allow time for the precipitate to form before reaching the filters.

With some fertilizers, like phosphates, if the injection is stopped an hour or so before the end of the irrigation cycle, there is a better chance of flushing out the chemicals before they have a chance to react and form precipitates.

Chapter 14 Environmental Concerns

Contents **NJ652.14**

NJ 652.14 Environmental Concerns

Refer to the National Irrigation Guide for material relating to the environmental concerns associated with irrigation.

The National Irrigation Guide, Chapter 14, discusses general environmental impacts, the pollution delivery process, types of pollutants, conservation practices for pollution control and reduction, and benefits and costs of irrigation.

Chapter 15 Tools and Worksheets

Exhibits

Exhibit NJ 15.1 Irrigation Site Evaluation Form
General Planning Data Worksheet
Exhibit NJ 15.2 Overhead Sprinkler Inventory Worksheet
Exhibit NJ 15.3 Drip Irrigation Inventory Worksheet
Exhibit NJ 15.4 IWM Data Worksheet
Exhibit NJ 15.5 Drip Irrigation Design Worksheet Vegetables/ Row Crops
Exhibit NJ 15.6 Drip Irrigation Design Worksheet Orchards, Berries, Vineyards
Exhibit NJ 15.7 Sprinkler Irrigation Design Worksheet
Exhibit NJ 15.8 Traveling Gun Irrigation Design Worksheet
Exhibit NJ 15.9 Center Pivpt/Linear Move Irrigation Design Worksheet
Exhibit NJ 15.10 Spreadsheet Format: Drip Irrigation Design, Vegetables
Exhibit NJ 15.11 Spreadsheet Format: Drip Irrigation Design, Orchards, Berries and Vineyards
Exhibit NJ 15.12 Spreadsheet Format: Microsprinkler Irrigation Design
Exhibit NJ 15.13 Spreadsheet Format: Sprinkler Irrigation Design
Exhibit NJ 15.14 Spreadsheet Format: Hoophouse Sprinkler Irrigation Design
Exhibit NJ 15.15 Spreadsheet Format: Center Pivot Irrigation Design
Exhibit NJ 15.16 Spreadsheet Format: Linear Move Irrigation Design
Exhibit NJ 15.17 Spreadsheet Format: Traveling Gun Irrigation Design
Exhibit NJ 15.18 IWM Data Sheet

IRRIGATION SITE EVALUATION FORM
GENERAL PLANNING DATA WORKSHEET

RESOURCE DATA

- **Total Acres That Require Irrigation** ________________
- **Type of Crops** ________________
- **Row Spacing** ________________
- **Plant Spacing** __________ _______
- **Soils: Series** ___________ **Texture**____________
- **Topography (Elevations In Field And At Water Supply)** _________________
- **Aerial Photo With Existing and Proposed Irrigation Layout and Row Direction**

WATER SUPPLY: **Existing** ________ **Proposed** ________ ____

- **Type** **well pond other**
- **Location** _______________
- **Capacity and Acres Irrigated** ______**gmp** ______**acres**
- **Water Quality** _______________ **(ex. iron, algae, salt, other)**
- **Pump Type:** **Centrifugal** _____ **Submersible** _____ **Turbine**___
- **Pump Model:** ______ __________
- **Static Water Level** ________________
- **Drawdown Level After Pump Is Running** ________________ **(from well record)**

IRRIGATION SYSTEM

- **Currently Irrigating** _______ **Never Irrigated**_________
- **Is Irrigation Needed?** _____
- **Type Of Existing Irrigation Syst em** _________________
- **Type Of New Irrigation System** ________________
- **Existing Mainline: Size** _____ **Material**_________
- **Proposed Mainline: Size** _____ **Material**_________

COMPUTE CAPACITY REQUIREMENTS FOR IRRIGATED ACREAGE

$$Q = \frac{453 \cdot DA}{T}$$

where **Q=gpm D =depth (use .2"divided by system efficiency)**
A= acres T= time (use 22 hours)

Q = ______gpm

DEP Water Allocation Certification Yes (>70gpm) No (<70gpm)

IRRIGTION WATER MANAGEMENT

Existing Water Management Practices: ______________ _______________________
Proposed: ____
Chemigation / Fertigation (Circle) Yes No

- **Chemigation Valve or Backflow Preventers** **Type** _________ **Size** ______
- **Flowmeter:** **Type** _________ **Size** ______
- **Soil Moisture Sensors** **Type** _________ **Depth** _____
- **Weather Station Network (Circle)** **Yes** **No**

OVERHEAD SPRINKLER INVENTORY WORKSHEET

TRACT # ____
TYPE OF CROPS ____
PUMP TYPE / MODEL # / CURVE _____________ ______________
PUMP CAPACITY __________GPM

SPRINKLER SYSTEM TYPE: Existing (acres) Proposed (acres)

- **Hand Move Sprinkler _____ ______**
- **Solid Set Sprinkler _____ ______**
- **Traveling Gun _____ ______**
- **Stationary Gun _____ ______**
- **Center Pivot _____ ______**
- **Linear Move _____ ______**
- **Other _____ ______**

SYSTEM DATA - SPRINKLERS

- **Sprinkler Nozzle Size / Manufacturer ________**
- **Flow Rate ________gpm**
- **Nozzle Pressure ________psi**
- **Sprinkler Spacing ________ft**
- **Lateral Spacing ________ft**
- **Riser Spacing ________ft**
- **Mainline Pipe Diameter and Length ________in _________ft**
- **Submain Pipe Diameter and Length ________in _________ft**
- **Lateral Pipe Diameter ________in**
- **Number of Sprinklers/Zone ________**
- **Pump Pressure ________psi**

SYSTEM DATA – TRAVELER/GUN

- **Gun Model # ________**
- **Nozzle Size ________in**
- **Flow Rate ________gpm**
- **Water Winch Manufacturer and Model ________**
- **Hose Diameter (ID) ________in**
- **Hose Length ________ft**
- **Nozzle Pressure / Reel Pressure /Pump Pressure ______ _____ ____psi**

SYSTEM DATA – PIVOT / LINEAR MOVE

- **Manufacturer/ Model # _________**
- **Sprinkler Type / Manufacturer and Model _________ ___________**
- **Lateral Length _________ft**
- **Pressure Regulators / Model _________psi**
- **Pressure at Pivot _________psi**
- **Pump Pressure _________psi**
- **Sprinkler Package (from manufacturer) _________**

DRIP IRRIGATION INVENTORY WORKSHEET

TRACT # ________________________
TYPE OF CROPS ____
PUMP TYPE/MODEL/CURVE ________ __________ _________
PUMP CAPACITY ______________GPM

ACRES OF *EXISTING* DRIP IRRIGATION ____________
TYPE OF *EXISTING* DRIP SYSTEM:
- **Tape (Annual Crops/Short Term Irrigation) _____**
- **Hose (Perennial Tree Fruit, Small Fruit, Vines) _____**
- **Micro-sprinkler (Perennial Tree Fruit) _____**

ACRES OF DRIP IRRIGATION *PROPOSED* ____________
TYPE OF DRIP SYSTEM *PROPOSED*:
- **Tape (Annual Crops/Short Term Irrigation) _____**
- **Hose (Perennial Tree Fruit, Small Fruit, Vines) _____**
- **Micro-sprinkler (Perennial Tree Fruit) _____**

SYSTEM DATA
- **Emitter Manufacturer and Model __________________**
- **Emitter Flow Rates _________**
- **Emitter Pressure _________**
- **Emitter Spacing _________**
- **Lateral Spacing _________**
- **Mainline Pipe Diameter _________**
- **Submain Pipe Diameter _________**
- **Lateral Diameter _________**
- **Lateral Length _________**
- **Number Of Zones _________**
- **Zone Size/Flow Rate _________**
- **Location And Type Of Control Valves _________ _________**
- **Location Of Filter Station _________**
- **Filters – Type And Size _________ _________**
- **Chemigation Valves or Backflow Preventers _________**
- **Flowmeter Type _______ Size ______**
- **Preset Pressure Regulators – Pressure/Flow Rate ________/___________**
- **Pressure Reducing Valves - Location___________ Size _____**
- **Air and Vacuum Relief – Location _______ Size _____**
- **Manufacturer Data Sheets For System ___________**

IWM DATA WORKSHEET
TRACT # _________

RESOURCE DATA

- **Total Acres That Require Irrigation** _________________
- **Type of Crops** _________________
- **Row Spacing** _________________
- **Plant Spacing** _________________
- **Soils: Series ___________ Texture____________**
- **Topography (Elevations difference between field and water supply) _____________**
- **Aerial Photo With Existing and Proposed Irrigation Layout and Row Direction**

WATER SUPPLY: Existing ________ Proposed ________

- **Type well pond other**
- **Capacity and Acres Irrigated ______gpm ______acres**
- **Water Quality _______________(ex. iron, algae, salt, other)**
- **Pump Type: Centrifugal _____ Submersible _____ Turbine___**
- **Pump Model: _________________**
- **Static Water Level _________________**
- **Drawdown Level After Pump Is Running ________________(from well record)**

COMPUTE CAPACITY REQUIREMENTS FOR IRRIGATED ACREAGE

$$Q = \frac{453*DA}{T}$$

where **Q=gpm D=depth (use .2”divided by system efficiency)**
A= acres T= time (use 22 hours)

Q = ______gpm

DEP Water Allocation Certification Yes (>70gpm) No (<70gpm)

SYSTEM TYPE:	**Existing (acres)**	**Proposed (acres)**
➢ **Drip (90% Eff.)**	_____	______
➢ **Hand Move Sprinkler (70% Eff.)**	_____	______
➢ **Solid Set Sprinkler (75% Eff.)**	_____	______
➢ **Traveling Gun (65% Eff.)**	_____	______
➢ **Stationary Gun (60% Eff.)**	_____	______
➢ **Center Pivot (85% Eff.)**	_____	______
➢ **Linear Move (85 % Eff.)**	_____	______
➢ **Other**	_____	______

SYSTEM DATA - DRIP

- ➢ **Emitter Manufacturer and Model** ________________________
- ➢ **Emitter Flow Rates and Pressure** _________ _________psi
- ➢ **Emitter Spacing** _________
- ➢ **Lateral Spacing** _________ft
- ➢ **Lateral Diameter** _________in
- ➢ **Filters – Type And Size** _________ _________
  (Sand filters, disc and screen filters with automatic backwash for surface water supplies. Manual flush for ground water supplies)
- ➢ **Preset Pressure Regulators – Pressure/Flow Rate ________psi ___________gpm**
- ➢ **Pump Pressure ________psi**

<u>SYSTEM DATA - SPRINKLERS</u>

- **Sprinkler Manufacturer and Nozzle Size** ________ ________
- **Flow Rate** ________gpm
- **Nozzle Pressure** ________psi
- **Sprinkler Spacing** ________ft
- **Lateral Spacing** ________ft
- **Riser Spacing** ________ft
- **Lateral Pipe Diameter** ________in
- **Pump Pressure** ________psi

<u>SYSTEM DATA – TRAVELER/GUN</u>

- **Water Winch Manufacturer and Model** ________
- **Nozzle Size** ________in
- **Flow Rate** ________gpm
- **Gun Model #** ________
- **Hose Diameter (ID)** ________in
- **Hose Length** ________ft
- **Riser Spacing** ________ft
- **Nozzle Pressure / Reel Pressure /Pump Pressure** ______ _____ ____psi

<u>SYSTEM DATA – PIVOT / LINEAR MOVE</u>

- **Manufacturer / Model #** _________
- **Sprinkler Type / Manufacturer / Model** _________ ___________
- **Lateral Length** _________ft
- **Distance from Pivot point to outer drive wheel** _________ft
- **Pressure Regulators / Model and Pressure** _________ _________psi
- **Pressure at Pivot** _________psi
- **Pump Pressure** _________psi
- **Sprinkler Package (from manufacturer) or Sprinkler spacing at middle of lateral** _________ft
- **End Gun Manufacturer / Model** _________
- **End Gun Nozzle Size / Pressure** _________in __________psi

<u>IRRIGATION SYSTEM LAYOUT</u> - (Provide sketch with dimensions or drawing to scale)

- **Type of irrigation system**
- **Field boundaries, pipeline, risers, valves, submain and laterals**
- **Mainline layout from water source to each field or zone**
- **Pipe sizes and lengths**
- **Zone Size/Flow Rate (Drip)**
- **Number of Sprinklers/Zone**
- **Spacing of Laterals and Emission Devices**
- **Number of laterals with corresponding pipe size for each field or zone**
- **Location of pump, pond and/or well, filters, injection pumps, air and vacuum relief valves.**

DRIP IRRIGATION DESIGN WORKSHEET
VEGETABLES/ROW CROPS

COOPERATOR: ____________________ **DATE: _______**

COUNTY: _____________ **TWP: _________**

Checked: _____ **Approved: ________**

CROP DATA

- TYPE: _________
- ROOT ZONE DEPTH: ________(NJ Irr. Guide, Table NJ 3.3)
- SPACING BETWEEN PLANTS: ___________ (ft)
- ROW SPACING: ________(ft)
- WIDTH OF CANOPY COVER: _____(ft)
- % FOLIAGE COVERAGE: ________(canopy cover ft / row spacing ft x 100)
- CROP Etc: _____________(in/day)
  = Eto inches/day x Kc. Where Kc = .8 of daily pan (Eto)
  (Eto = .2 in/day or use avg. daily Et from local weather stations posted on internet site: www.sjrcd.org)

- NET GALLONS/DAY REQUIRED per 100 feet = ___________(gallons/day)
  50 x Eto in/day x row spacing (ft)

- GROSS IRRIGATION REQUIREMENTS per 100 feet = __________(gallons/day)
  net gallons/day required per 100 feet / irrigation efficiencies

SOILS DATA

- SERIES: ___________

- APPLICATION RATE: ________ (NJ Irr.Guide, Table NJ 2.1)

- AVAILABLE WATER CAPACITY: _______ (inches) (NJ Irr.Guide, Table NJ 2.1)

- AMOUNT TO APPLY (25% DEPLETION): ______ (inches) **(available water capacity * 25%)**

- SOIL MOISTURE TENSION: _______*cb* (NJ Irr. Guide, Table NJ 9.3)

DESIGN DATA

- TYPE OF DRIP LINE: __________(manufacturer spec sheets)
- MANUFACTURER MODEL: ________(manufacturer spec sheets)
- LATERAL DIAMETER/THICKNESS: _________(manufacturer spec sheets)
- EMITTER TYPE: _______(manufacturer spec sheets)
- FLOW RATE: _____(gal/hr) (convert to gpm) _____ gal/min = **(gal/hr x 1hr/60min)**
- DESIGN PRESSURE: ____(psi) (manufacturer spec sheets)
- PC ___ OR Non PC ____ (check)
- RECOMMENDED PRESSURE RANGE: ___________(manufacturer spec sheets)
- MAXIMUM LATERAL LENGTH: _________(measure maximum row length)
- EMITTER SPACING: _______(in)
- EMITTERS/PLANT: _______
  spacing between plants / emitter spacing
- WETTED DIAMETER/EMITTER: ______(Ft) (NJ Irr. Guide, Table 6.10)
- WETTED AREA/PLANT: ____________(SqFt)
  = # of emitters/plant x emitter spacing x emitter wetted diameter
- % ROOT ZONE AREA WETTED: _______% (must meet 25% - 60%)
  = (wetted diameter/emitter / width of canopy cover) x 100
- GAL/MINUTE/ACRE: ________ = **43560 sqft x gpm/emitter / emitter spacing(ft) x row spacing(ft)**

APPLICATION RATES, RUN TIME, AND FREQUENCY CALCULATIONS

- APPLICATION RATE:_______(*in/hr*) = **96.3 x gpm/emitter / emitter spacing(ft) x row spacing(ft)**

NET APPLICATION RATE: ______(*in/hr*) = **application rate x efficiency/100**

- ESTIMATED IRRIGATION TIME: ____________(hr/day)
  gross irrigation requirements per 100 feet / tape flow rate (gallons per hr/100')

- IRRIGATION FREQUENCY (*days)*:
  (Based On Management Allowed Depletion)

  = Inches to be applied at Mgt. Allowed Depletion (25% Depletion)
  Eto"/day x Kc

  =___________*days*

- TOTAL HOURS OF IRRIGATION AT MGT. ALLOWED DEPLETION:

  = Irrigation Frequency (Days) x estimated irrigation time (Hrs/Day)

  = ________*hrs*

CAPACITY REQUIREMENTS FOR IRRIGATION SYSTEM

QT = DA

Gallons per minute, Q = 453 x Acres irrigated *(A)* x inches of water required *(D)*
Time in hours *(T)*

(Reference - NJIG pg. 6.35, Figure 6.2)

Q = gallons/minute - pumping capacity
D = net depth of irrigation (in inches) divided by system efficiency (as a decimal).
A = total area to be irrigated (acres)
T = total time required in hours to complete irrigation cycle (22 hr. irrigation day)

Show calculation:

= ______________gallons/minute

CHECK SYSTEM DESIGN

DESIGN CAPACITY - ________*gpm*

SIZE OF MAINLINE - ________ Maximum Flow *(not to exceed 5fps)* - ______

SIZE OF SUBMAIN - _______ Maximum Flow *(not to exceed 5fps)* - ________

FRICTION LOSSES

TYPE OF LOSSES	PIPE SIZE	TOTAL FLOW GPM	LENGTH	FRICTION LOSSES PER 100’	CUM. LOSSES PSI
Mainline					
Submain					
Lateral					
Filter					
Static (Elevation)					
Fitting – 5%					
TOTAL LOSSES					

Avg.Emitter Pressure					
*Pump Operating Pressure					

*Pump Operating Pressure = Avg. Emitter Pressure + Total Pressure Losses

INSERT VALUES FROM FRICTION LOSS SOFTWARE PROGRAM IF AVAILABLE.

PUMP DATA

TYPE: _______

MANUFACTURER MODEL #: _________

RATED DISCHARGE GPM: _________

DESIGN DISCHARGE RATE: _________

TOTAL DYNAMIC HEAD:
Static Head (ft) (drawdown level) or Suction Lift + Pump Pressure (psi) x $\frac{2.31'}{\text{Psi}}$
= __________FT

PUMP EFFICIENCY: _______ (Pump Curve)

BRAKE HORESPOWER: ________ TDH x Flow Rate/ 3960 x efficiency
POWER SOURCE: ________

DOES PUMP MEET IRRIGATION REQUIREMENT? ____ YES ____NO

OPERATE PUMP AT ________PSI TO DELIVER ________*gpm*

OPERATE PRESSURE REGULATING VALVE AT _______*psi*

PRESSURE RANGE WITHIN ZONE: ________________

FERTIGATION AND CHEMIGATION - YES OR NO
TYPE OF INJECTOR:
RATE OF INJECTION:
TYPE OF BACKFLOW PREVENTION DEVICE:

PRESSURE /FLOW VARIATION

NON-PRESSURE COMPENSATING EMITTERS
Examples: Netafim Python, Triton, Streamline, and Typhoon; T Tape
Check manufacturer specification sheet for pressure range and EU curves.

Design Pressure - ________

Recommended Pressure Range - _________

Pressure Variation - _______

Discharge Variation - ______ (must meet +/- 15% variation)

NOTE: FOR NON-PC EMITTERS A 30% PRESSURE VARIATION WILL RESULT IN 20% FLOW VARIATION, (+/- 10%) ALONG LATERAL LINE.
WITHIN THE FIELD/ZONE, A 45% PRESSURE VARIATION WILL RESULT IN 30% FLOW VARIATION (+/- 15% VARIATION OR 85% EU).

PRESSURE COMPENSATING EMITTERS
Examples: Netafim Ram; Wade Rain; Drip In; Rainbird PC
Check Manufacturer specification sheet for Pressure range and EU curves

Design Pressure - ________

Recommended Pressure Range - _________

Pressure Variation - _______

Discharge Variation - ______ (must meet +/- 15% variation)

NOTE: FOR PC EMITTERS 80% or more PRESSURE VARIATION WILL RESULT IN 20% FLOW VARIATION, (+/- 10%). Refer to Manufacturer sheets.

____ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.

____ SYSTEM MEETS, BUT CHANGES ARE RECOMMENDED TO IMPROVE EFFICIENCY.

____ SYSTEM DOES NOT MEET NRCS STANDARDS AND SPECS. REFER TO ATTACHED SHEET FOR RECOMMENDED DESIGN CHANGES.

DRIP IRRIGATION DESIGN WORKSHEET
ORCHARDS, BERRIES, VINEYARDS

COOPERATOR: ____________________ **DATE: _______**

COUNTY: ____________ **TWP: ________**

Checked: _____ **Approved: ________**

CROP DATA

- TYPE: _________
- ROOT ZONE DEPTH: ________ (NJ Irr. Guide, TableNJ 3.3)
- ROW SPACING: ________(ft)
- SPACING BETWEEN PLANTS: ___________(ft)

- SURFACE AREA: ______(sqft) **(row spacing * spacing between plants)**
- CANOPY COVER: _____(sqft) **(Grapes; spacing between plants * 2', all other crops; spacing between plants^2 * π ÷ 4)**
- % GROUND SHADE ________(%) **(canopy cover sqft / surface area sqft x 100)**
- CROP DEVELOPMENT COEFFICENT *(Kc1)*: _____________
  (for peak demand use: 1.0 for orchards, 1.1blueberries, .8 for grapes)
- CANOPY COEFFICENT *(Kc2):* ________ (NJ Irr. Guide, Table NJ 6.26)

- PEAK PLANT WATER USE (net):
  = ____ (Eto *in/day*) x ___(Kc1) x ___(Kc2*) x* _______(surface area *sqft) x .623*
  (Eto = .2 in/day or use avg. daily Et from local weather stations posted on internet site www.sjrcd.org)

  = _____________*Gal/Day/Plant* (net)

- GROSS IRRIGATION REQUIREMENTS ______________*Gals/Day/Plant*

$$= \frac{\textbf{Gallons/Day/Plant (net)}}{\textbf{Irrigation Efficiency (\textit{use .90})}}$$

SOILS DATA

- SERIES: ___________
- APPLICATION RATE: ________ (in/hr) (NJ Irr.Guide, Table NJ 2.1)
- AVAILABLE WATER CAPACITY: _______(inches) (NJ Irr.Guide, Table NJ 2.1)
- AMOUNT TO APPLY (25% DEPLETION): ______(inches) **(available water capacity * 25%)**

DESIGN DATA

- TYPE OF DRIP LINE: ___________ (manufacturer spec sheets)
- MANUFACTURER MODEL: _________ (manufacturer spec sheets)
- LATERAL DIAMETER/THICKNESS: __________ (manufacturer spec sheets)
- EMITTER TYPE: ________ (manufacturer spec sheets)
- FLOW RATE (per emitter): ______ (gal/hr) convert to gpm ______ (gal/min) = **(gal/hr x $\frac{1hr}{60min}$)**
- DESIGN PRESSURE: _____ (psi) (manufacturer spec sheets)
- PC ____ OR Non PC _____ (check)
- RECOMMENDED PRESSURE RANGE: ____________ (manufacturer spec sheets)
- MAXIMUM LATERAL LENGTH: __________ (measure maximum row length)
- EMITTER SPACING: ________
- EMITTERS/PLANT: ________ **(plant spacing in row / emitter spacing)**
- GALLONS/HR/PLANT (gross):________ **(gph/emitter x # of emitters/plant)**
- WETTED DIAMETER/EMITTER: _______ (ft) (NJ Irr. Guide, Table NJ 6.19)
- WETTED AREA/PLANT: _____________(sqft)
  = **# of emitters/plant x emitter spacing x emitter wetted diameter**
- % ROOT ZONE AREA WETTED: ________ (%) (must be at least 25%)
  = **$\frac{\text{\# of emitters/plant x emitter spacing x wetted diameter of emitter x 100}}{\text{canopy area}}$**
- GAL/MINUTE/ACRE: _________ = **$\frac{\text{43560 sqft x gpm/emitter}}{\text{emitter spacing(ft) x row spacing(ft)}}$**

APPLICATION RATES, RUN TIME, AND FREQUENCY CALCULATIONS

- APPLICATION RATE:________ *(in/hr)* = **$\frac{\text{96.3 x gpm/emitter}}{\text{emitter spacing(ft) x row spacing(ft)}}$**
- NET APPLICATION RATE: _______ *(in/hr)*
  = **application rate x efficiency/100 ÷ canopy coefficent**

- DAILY RUN TIME:(Compute Both Ways)

  = **Gross Gals/Plant/Day / Gross Gals/Hr/Plant** or **Eto"/day x Kc1 / Net Application Rate (in/hr)**

  = __________ (*hrs/day*) =___________ *(hrs/day)*

- IRRIGATION FREQUENCY (*days)*:
  (Based On Management Allowed Depletion)

  = **Inches to be applied at Mgt. Allowed Depletion / Eto"/day x Kc1**

  =___________ (*days)*

- TOTAL HOURS OF IRRIGATION AT MGT. ALLOWED DEPLETION:

  = **Irrigation Frequency (Days) x Daily Run Time (Hrs/Day)**

  = ________ (*hrs)*

CAPACITY REQUIREMENTS FOR IRRIGATION SYSTEM

QT = DA

Gallons per minute, Q = 453 x Acres irrigated *(A)* x inches of water required *(D)* / Time in hours *(T)*

(Reference - NJIG pg. 6.35, Figure 6.2)

Q = gallons/minute - pumping capacity
D = net depth of irrigation (in inches) divided by system efficiency (as a decimal).
A = total area to be irrigated (acres)
T = total time required in hours to complete irrigation cycle (22 hr. irrigation day)

Show calculation:

= ______________ (gpm)

CHECK SYSTEM DESIGN

DESIGN CAPACITY - ________ (*gpm)*

SIZE OF MAINLINE - ________ Maximum Flow *(not to exceed 5fps)* - ______

SIZE OF SUBMAIN - _______ Maximum Flow *(not to exceed 5fps)* - ________

FRICTION LOSSES

TYPE OF LOSSES	PIPE SIZE	TOTAL FLOW GPM	LENGTH	FRICTION LOSSES PER 100'	CUM. LOSSES PSI
Mainline					
Submain					
Lateral					
Filter					
Static (Elevation)					
Fitting – 5%					
TOTAL LOSSES					

Avg.Emitter Pressure					
*Pump Operating Pressure					

*Pump Operating Pressure = Avg. Emitter Pressure + Total Pressure Losses

INSERT VALUES FROM FRICTION LOSS SOFTWARE PROGRAM IF AVAILABLE.

PUMP DATA

TYPE: _______

MANUFACTURER MODEL #: _________

RATED DISCHARGE GPM: _________

DESIGN DISCHARGE RATE: _________

TOTAL DYNAMIC HEAD:

Static Head (ft) (drawdown level) or Suction Lift + Pump Pressure (psi) x $\frac{2.31'}{\text{Psi}}$

= __________FT

PUMP EFFICIENCY: _______ (Pump Curve)

BRAKE HORESPOWER: ________ TDH x Flow Rate/ 3960 x efficiency
POWER SOURCE: ________

DOES PUMP MEET IRRIGATION REQUIREMENT? ____ YES ____NO

OPERATE PUMP AT ________ (psi) TO DELIVER ________ (*gpm)*

OPERATE PRESSURE REGULATING VALVE AT _______ (*psi)*

PRESSURE RANGE WITHIN ZONE: ________________

FERTIGATION AND CHEMIGATION - YES OR NO
TYPE OF INJECTOR:
RATE OF INJECTION:
TYPE OF BACKFLOW PREVENTION DEVICE:

PRESSURE /FLOW VARIATION

NON-PRESSURE COMPENSATING EMITTERS
Examples: Netafim Python, Triton, Streamline, and Typhoon; T Tape
Check manufacturer specification sheet for pressure range and EU curves.

Design Pressure - ________

Recommended Pressure Range - _________

Pressure Variation - _______

Discharge Variation - ______ (must meet +/- 15% variation)

NOTE: FOR NON-PC EMITTERS A 30% PRESSURE VARIATION WILL RESULT IN 20% FLOW VARIATION, (+/- 10%) ALONG LATERAL LINE.
WITHIN THE FIELD/ZONE, A 45% PRESSURE VARIATION WILL RESULT IN 30% FLOW VARIATION (+/- 15% VARIATION OR 85% EU).

PRESSURE COMPENSATING EMITTERS
Examples: Netafim Ram; Wade Rain; Drip In; Rainbird PC
Check Manufacturer specification sheet for Pressure range and EU curves

Design Pressure - ________

Recommended Pressure Range - _________

Pressure Variation - _______

Discharge Variation - ______ (must meet +/- 15% variation)

NOTE: FOR PC EMITTERS 80% or more PRESSURE VARIATION WILL RESULT IN 20% FLOW VARIATION, (+/- 10%). Refer to Manufacturer sheets.

____ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.

____ SYSTEM MEETS, BUT CHANGES ARE RECOMMENDED TO IMPROVE EFFICIENCY.

____ SYSTEM DOES NOT MEET NRCS STANDARDS AND SPECS. REFER TO ATTACHED SHEET FOR RECOMMENDED DESIGN CHANGES.

SPRINKLER IRRIGATION DESIGN WORKSHEET

COUNTY: _____________ **WATERSHED: _____________**

COOPERATOR: ________ **Date: _______**

Checked: _____ **Approved: ________**

CROP DATA

- TYPE: _________
- ROW SPACING: ________
- ROOT ZONE DEPTH: ________ (NJ Irr. Guide, Table 3.3)
- CONSUMPTIVE USE: _____in/day
  (Et = .2 in/day or use avg. daily Et from local weather stations posted on intenet site: www.sjrcd.org)

SOILS DATA

- SERIES: ___________
- APPLICATION RATE: ________ (NJ Irr.Guide, Table 2.1)
- AVAILABLE WATER CAPACITY: _______inches (NJ Irr.Guide, Table 2.1)
- MAXIMUM ALLOWABLE DEFICIENCY: ______%(MAD)
- NET IRRIGATION REQUIRED: ______
- IRRIGATION FREQUENCY: _______ = Net Irrigation / daily ET

DESIGN DATA

- TYPE OF SPRINKLER __________
- MANUFACTURER MODEL: ________
- DESIGN FLOW RATE (gpm): _____
- DESIGN PRESSURE: ____
- WETTED DIAMETER: ____
- SPRINKLER SPACING: _______
- GAL/MINUTE/ACRE: ______
- APPLICATION RATE:_______in/hr = $\frac{96.3 \times gpm}{spacing (Ft)}$
- POTENTIAL SYSTEM EFFICIENCY % __________
- NET IRRIGATION REQUIRED _________
- GROSS IRRIGATION: ______inches = $\frac{\text{Net Irr. Req. (50\% depletion)}}{\text{System Efficiency}}$
- HOURS OF IRRIGATION: _____ = $\frac{\text{Gross Irr. Required}}{\text{rate of application in/hr}}$
- IRRIGATION FEQUENCY: _____

SPRINKLER DESIGN SYSTEM CHECK

DESIGN CAPACITY - ________GPM

SIZE OF MAINLINE - ________ MAXIMUM FLOW *(not to exceed 5fps)* - ______

SIZE OF SUBMAIN - _______ MAXIMUM FLOW *(not to exceed 5fps)* - ______

MAXIMUM SPRINKLERS/ZONE - __________

CAPACITY REQUIREMENTS FOR IRRIGATION SYSTEM

QT = DA

Gallons per minute, $Q = \dfrac{453 \times \text{Acres irrigated } (A) \times \text{ inches of water required } (D)}{\text{Number of days} \times \text{Hours per day } (T)}$

Reference - NJIG pg. 6.35, Figure 6.2

Q = gallons/minute - pumping capacity

D = gross irrigation required

A = total area to be irrigated (acres)

T = total time required in hours to complete irrigation cycle(18 hr. irrigation day)

SHOW CALCULATION:

PUMP DATA:

TYPE : _______

MANUFACTURER MODEL #: _________

RATED DISCHARGE GPM: _________GPM

DESIGN DISCHARGE RATE: _________GPM

PUMPING LIFT /STATIC HEAD ________ FT

TOTAL DYNAMIC HEAD (TDH): _________FT

PUMP EFFICIENCY: _______

BRAKE HORSEPOWER __________ $\dfrac{\text{GPM X TDH}}{\text{3960 X PUMP EFFICIENCY}}$

POWER SOURCE: ________

FRICTION LOSSES

TYPE OF LOSSES	SIZE OF PIPE	TOTAL FLOW GPM	LENGTH	FRICTION LOSSES PER 100’	CUM. LOSSES PSI	CUM. HEAD LOSSES
MAINLINE						
SUBMAIN						
LATERAL						
STATIC						
FITTING						
TOTAL PSI LOSSES						
PUMP SUCTION LIFT (FT)						
PUMP DISCHARGE HEAD/PRES.						
TOTAL DYNAMIC HEAD						

INSERT VALUES FROM FRICTION LOSS SOFTWARE PROGRAM IF AVAILABLE.

Pump discharge pressure must be < 72% of pipe pressure rating.
Lateral line losses must be < 20% of design pressure at nozzle.

____ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.

____ SYSTEM MEETS, BUT CHANGES ARE RECOMMENDED TO IMPROVE EFFICIENCY.

____ SYSTEM DOES NOT MEET NRCS STANDARDS AND SPECS. REFER TO ATTACHED SHEET FOR RECOMMENDED DESIGN CHANGES.

TRAVELING GUN

IRRIGATION DESIGN WORKSHEET

COOPERATOR: ___________________ **Date: _______**

COUNTY: _____________ **TWP: ____________**

Checked: _____ **Approved: ________**

CROP DATA

- ACRES IRRIGATED: ________
- TYPE: _________
- ROOT ZONE DEPTH: ________ (NJ Irr. Guide, Table 3.3)
- CONSUMPTIVE USE: _____in/day
  (Et = .2 in/day or use avg. daily Et from local weather stations posted on internet site: www.sjrcd.org)

SOILS DATA

- SERIES: ___________
- APPLICATION RATE: ________ (NJ Irr.Guide, Table 2.1)
- AVAILABLE WATER CAPACITY: _______inches (NJ Irr.Guide, Table 2.1)
- MAXIMUM ALLOWABLE DEFICIENCY: 50%(MAD)
- NET IRRIGATION REQUIRED: ______
- IRRIGATION FREQUENCY: _______ = $\frac{\text{Net Irrigation}}{\text{daily ET}}$

DESIGN DATA

- TYPE /SIZE OF NOZZLE : __________
- MANUFACTURER MODEL: ________
- TRAVELER MODEL: ___________
- HOSE INNER DIAMETER AND LENGTH: _______ _______
- DESIGN FLOW RATE : _____gpm
- DESIGN PRESSURE: ____psi
- WETTED DIAMETER: ____ft
- WETTED RADIUS (t) _________ft
- TOWPATH (RISER)SPACING: _______
  (50% - 60% of wetted diameter for 5 –10mph wind speed)
- SPEED OF TRAVELER: ________FT/MIN
- APPLICATION RATE:_______in/hr = $\frac{96.3 \text{ x gpm}}{\pi(.9t)^2} \text{ x } \frac{360°}{320°}$
  t = wetted radius
- GROSS IRRIGATION: ______inches = $\frac{1.605 \text{ x Q}}{\text{spacing x speed of traveler}}$
- SYSTEM EFFICIENCY: _____ %
- NET IRRIGATION APPLIED: _______inches = Gross irr. x system efficiency

SYSTEM DESIGN CHECK

DESIGN CAPACITY - ________GPM

SIZE OF MAINLINE - ________ MAXIMUM FLOW *(not to exceed 5fps)* - ______

SIZE OF SUBMAIN - _______ MAXIMUM FLOW *(not to exceed 5fps)* - ______

MAXIMUM SPRINKLERS/ZONE - __________

CAPACITY REQUIREMENTS FOR IRRIGATION SYSTEM

QT = DA

Gallons per minute, $Q = \frac{453 \times \text{Acres irrigated } (A) \times \text{ inches of water required } (D)}{\text{Number of days} \times \text{Hours per day } (T)}$

(Reference - NJIG pg. 6.35, Figure 6.2)
Q = gallons/minute - pumping capacity
D = net depth irrigation (in inches) divided by system efficiency (as a decimal)
A = total area to be irrigated (acres)
T = total time required in hours to complete irrigation cycle(22 hr. irrigation day)

SHOW CALCULATION:

FRICTION LOSSES

TYPE OF LOSSES	SIZE OF PIPE	TOTAL FLOW GPM	LENGTH	FRICTION LOSSES PER 100’	CUM. LOSSES PSI	CUM. HEAD LOSSES
MAINLINE						
SUBMAIN						
TRAVELER HOSE						
STATIC						
FITTING						
TOTAL PSI LOSSES						
NOZZLE PRESSURE						
PUMP DISCHARGE HEAD/PRES. (TOTAL PSI LOSSES + NOZZLE)						
PUMP SUCTION LIFT (FT)						
TOTAL DYNAMIC HEAD						

Pump discharge pressure must be < 72% of pipe pressure rating.
INSERT VALUES FROM FRICTION LOSS SOFTWARE PROGRAM IF AVAILABLE.

PUMP DATA:

TYPE : _______

MANUFACTURER MODEL #: _________

RATED DISCHARGE GPM: _________ (PUMP) SYSTEM CAPACITY _____

TOTAL DYNAMIC HEAD: _________ (FT)

PUMP EFFICIENCY: _______%

BRAKE HORSESPOWER: ______ $\frac{\text{TDH x FLOW RATE}}{\text{3960 x EFFICIENCY}}$

POWER SOURCE: ________

HP HOURS/ GAL: ________ or KW HOURS/ GAL: _________

COST/HOUR RUN TIME: __________ (if data is available)

ATTACH COPY OF PUMP CURVE.

____ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.

____ SYSTEM MEETS, BUT CHANGES ARE RECOMMENDED TO IMPROVE EFFICIENCY.

____ SYSTEM DOES NOT MEET NRCS STANDARDS AND SPECS. REFER TO ATTACHED SHEET FOR RECOMMENDED DESIGN CHANGES.

CENTER PIVOT/LINEAR MOVE
IRRIGATION DESIGN WORKSHEET

COOPERATOR: ___________________ **Date: _______**
COUNTY: _____________ **TWP: ____________**
Checked: _____ **Approved: ________**

CROP DATA

- TOTAL ACRES: _____ ac
- ACRES IRRIGATED BY PIVOT WETTED RADIUS **(A)**: ________ ac
- TYPE: _________
- ROOT ZONE DEPTH: ________ **(NJ Irr. Guide, Table NJ 3.3)**
- CONSUMPTIVE USE **(ETc)**: _____in/day
  (**Et = .2 in/day or use avg. daily Et from local weather stations posted on internet site: www.sjrcd.org**)

SOILS DATA

- SERIES: ___________
- INTAKE FAMILY: ________ **(NJ Irr. Guide, Table NJ 2.2)**
- RESIDUE: _______ lbs/ac
- LAND SLOPE: ______ %
- AVAILABLE WATER CAPACITY: _______inches **(NJ Irr.Guide, Table NJ 2.1)**
- MAXIMUM ALLOWABLE DEFICIENCY: 50% **(MAD)**

DESIGN DATA

- PIVOT MAKE AND MODEL: _________

- SPRINKLER TYPE AND MODEL: __________
- SPRINKLER SPACING ALONG LATERAL: ________
- SYSTEM LENGTH **(L)**: _______ ft
- END GUN MODEL AND SIZE: ____________ _______ in
- END GUN FLOW RATE AND PRESSURE: ______ gpm ______ psi
- END GUN RADIUS **(ER)**: _______ft
- NUMBER OF TOWERS: ______
- PIVOT DESIGN FLOW RATE AND PRESSURE AT PIVOT **(Q)**: _____ gpm ____ psi
- CENTER PIVOT WETTED RADIUS **(R)**: ____ ft **(L + ER)**
- DISTANCE FROM CENTER PIVOT TO OUTER DRIVE WHEEL **(r)**: ________ ft
- WETTED DIAMETER OF LARGEST LATERAL NOZZLE **(w)**: ______ ft
- NOZZLE PRESSURE WITH REGULATOR: _______ psi
- SYSTEM EFFICIENCY: ______ % **(NJ Irr. Guide, Table NJ 4.4)**
- NET APPLICATION PER REVOLUTION: _____ in **(.5, .75, 1 or 1.25 in)**
- GROSS APPLICATION PER DAY **(D)**: ________ in **(ETc ÷ SYSTEM EFFICIENCY)**
- DESIGN GPM/ACRE: ______ gpm/ac **(Q / A)**
- MINIMUM GROSS IRRIGATION REQUIREMENT: ______ gpm/ac **(453 * D) / (22)**

  = (453 * ____) / 22 = ______ gpm/ac

  Note: Design gpm/ac must equal or exceed minimum irrigation requirements. If short, reduce acres or increase water supply.

- MAXIMUM ALLOWABLE APPLICATION RATE: ______ in/hr **(NJ Irr. Guide, Table NJ 2.3)**
- DESIGN APPLICATION RATE: ______ in/hr **(192.6 * r * Q) / (R^2 * w)**

  = (192.6 * ____ * ____) / (____^{2} * ____) = ______ in/hr

  Note: Design application rate must not exceed the maximum allowable application rate. Decrease flowrate or increase wetted diameter if needed.

FRICTION LOSSES

TYPE OF LOSSES	**SIZE OF PIPE**	**TOTAL FLOW GPM**	**LENGTH**	**FRICTION LOSSES PER 100'**	**CUM. LOSSES PSI**	**CUM. HEAD LOSSES**
MAINLINE						
PIVOT LATERAL **(P_L)**						
FILTER						
STATIC						
HEIGHT OF PIVOT						
FITTING						
TOTAL PSI LOSSES **(T_P)**						
PUMP DISCHARGE HEAD (psi) **(T_P - P_L + PRESSURE AT PIVOT)**						
PUMP SUCTION LIFT/PUMPING DEPTH (ft)						
TOTAL DYNAMIC HEAD (ft) **PUMP SUCTION LIFT + PUMP DISCHARGE HEAD**						

Pump discharge pressure must be < 72% of pipe pressure rating.
INSERT VALUES FROM FRICTION LOSS SOFTWARE PROGRAM IF AVAILABLE.

PUMP DATA:

TYPE : _______
MANUFACTURER MODEL #: _________
RATED DISCHARGE GPM: _________ (PUMP) SYSTEM CAPACITY _____
TOTAL DYNAMIC HEAD: _________ (FT)
PUMP EFFICIENCY: _______%
BRAKE HORSESPOWER: ______ $\frac{\text{TDH x FLOW RATE}}{\text{3960 x EFFICIENCY}}$
POWER SOURCE: ________
HP HOURS/ GAL: ________ or KW HOURS/ GAL: _________
COST/HOUR RUN TIME: __________ (if data is available)

ATTACH COPY OF PUMP CURVE.

____ **SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.**

____ **SYSTEM MEETS, BUT CHANGES ARE RECOMMENDED TO IMPROVE EFFICIENCY.**

____ **SYSTEM DOES NOT MEET NRCS STANDARDS AND SPECS. REFER TO ATTACHED SHEET FOR RECOMMENDED DESIGN CHANGES.**

DRIP IRRIGATION DESIGN
VEGETABLES

COOPERATOR: DATE:
COUNTY: TWP:
CHECKED: APPROVED:

CROP DATA

IRRIGATED ACRES:	ac
TYPE:	
ROOT ZONE DEPTH:	in
ROW SPACING:	ft
WIDTH OF CANOPY COVER:	ft
% FOLIAGE COVERAGE:	%
ETO:	in/day
GROSS IRRIGATION REQUIREMENTS (per 100'):	gal

SOIL DATA

SOIL TEXTURE:	
SERIES:	
APPLICATION RATE:	"/hr
AVAILABLE WATER CAPACITY:	in
AMOUNT TO APPLY:	in
IRRIGATION FREQUENCY (no rain):	days
TOTAL HOURS OF IRRIGATION:	hr
MOISTURE TENSION (cb):	

DESIGN DATA

IRRGATION PIPE LINE TYPE AND RATING:		psi
TYPE OF DRIP LINE:		
MANUFACTURER MODEL:		
LATERAL DIAMETER/THICKNESS:		
EMITTER TYPE:		
FLOW RATE:	gpm/100'	
DESIGN PRESSURE:	psi	
RECOMMENDED PRESSURE RANGE:	psi	
MAXIMUM LATERAL LENGTH:	ft	
EMITTER SPACING:	in	
WETTED DIAMETER/EMITTER:	ft	
% ROOT ZONE AREA WETTED:	%	
GAL/MINUTE/ACRE	gpm/ac	
APPLICATION RATE:	in/hr	
NET APPLICATION RATE (ROOT ZONE):	in/hr	
DAILY HOURS OF IRRIGATION:	hr/day	

MINIMUM CAPACITY REQUIRED FOR IRRIGATED ACRES:	gpm
PUMPING CAPACITY AVAILABLE:	gpm

FRICTION LOSSES

TYPE OF MAINLINE:		TOTAL FLOW (gpm)	LENGTH (ft)	FRICTION LOSSES (psi per 100')	CUM. LOSSES (psi)
MAINLINE (in)					
SUBMAIN (in)					
LATERAL					
FILTER					
HYDROCYCLONE					
STATIC (outside zone)					
STATIC (inside zone)					

PUMP DATA

TYPE:
MANUFACTURER MODEL #:
RATED DISCHARGE (gpm):
DESIGN DISCHARGE RATE (gpm):
SUCTION LIFT/COLUMN HT (ft):
TOTAL DYNAMIC HEAD (ft):
% PUMP EFFICIENCY:
BRAKE HORSE POWER (hp):
POWER SOURCE:

GAL/HR: KW/HR/HR:
COST/HOUR RUN TIME (base on current energy rates):
DIESEL ELECTRIC GASOLINE

OPERATE PUMP AT: **psi** **gpm**

PESSURE RANGE WITHIN ZONE: **psi**
FERTIGATION AND CHEMIGATION: YES ☐ NO ☐
TYPE OF INJECTOR:
RATE OF INJECTION (gph):
TYPE OF BACKFLOW PREVENTION DEVICE:

THRUST BLOCK AREA

PIPE SIZE	FITTING	PRESSURE	W (in)	L (in)	H (in)		

NOTE: NON PC EMITTERS NO MORE THEN 50% PRESSURE VARIATION ALLOWED TO MAINTAIN +/- 10% FLOW VARIATION.

☐ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.
☐ SYSTEM MEETS WITH RECOMMENDED CHANGES TO IMPROVE EFFICIENCY.
☐ SYSTEM DOES NOT MEET NRCS STANDARDS AND SPECS. REFER TO ATTACHED SHEET FOR RECOMMENDED DESIGN CHANGES

DRIP IRRIGATION DESIGN
Orchards, Berries, Vineyards

COOPERATOR: DATE:
COUNTY: TWP:
CHECKED: APPROVED:

CROP DATA

IRRIGATED ACRES:	ac
TYPE:	
ROOT ZONE DEPTH:	in
ROW SPACING:	ft
SPACING BETWEEN PLANTS:	ft
SURFACE AREA (sqft):	ft^2
CANOPY COVER (sqft):	ft^2
CANOPY COEFFICENT (Kc2):	
% FOLIAGE COVERAGE:	%
ETO:	
CROP COEFFICENT (Kc1):	
ETC:	
PEAK PLANT WATER USE (per day):	gal
GROSS IRRIGATION REQUIREMENTS (per day):	gal

SOIL DATA

SOIL TEXTURE:		
SERIES:		
APPLICATION RATE:		$^{"}/_{hr}$
AVAILABLE WATER CAPACITY:		in
AMOUNT TO APPLY:		in
IRRIGATION FREQUENCY (no rain):		days
TOTAL HOURS OF IRRIGATION:		hr
MOISTURE TENSION (cb):		

DESIGN DATA

IRRGATION PIPE LINE TYPE AND RATING:		psi
TYPE OF DRIP LINE:		
MANUFACTURER MODEL:		
LATERAL DIAMETER/THICKNESS:		
EMITTER TYPE:		
FLOW RATE:	$^{g}/_{hr}$	
DESIGN PRESSURE:	psi	
RECOMMENDED PRESSURE RANGE:	psi	
MAXIMUM LATERAL LENGTH:	ft	
EMITTER SPACING:	in	
# EMITTER/PLANT:		
WETTED DIAMETER/EMITTER:	ft	
WETTED AREA/PLANT:	ft^2	
% ROOT ZONE AREA WETTED:	%	
GAL/MINUTE/ACRE	$^{gpm}/_{ac}$	
APPLICATION RATE:	$^{in}/_{hr}$	
DESIGN AREA TO BE IRRIGATED:		
NET APPLICATION RATE (ROOT ZONE):	$^{in}/_{hr}$	
DAILY HOURS OF IRRIGATION:	$^{hr}/_{day}$	

MINIMUM CAPACITY REQUIRED FOR IRRIGATED ACRES:	gpm

FRICTION LOSSES

TYPE OF MAINLINE:		TOTAL FLOW (gpm)	LENGTH (ft)	FRICTION LOSSES (psi per 100')	CUM. LOSSES (psi)
MAINLINE (in)					
SUBMAIN (in)					
LATERAL					
FILTER					
HYDROCYCLONE					
STATIC (outside zone)					
STATIC (inside zone)					
FITTING (%)					
TOTAL					
TOTAL PRESSURE LOSSES IN ZONE					
END LATERAL PRESSURE					
REGULATE ZONE AT					
MINIMUM OPERATED PRESSURE AT PUMP					

PUMP DATA

TYPE:	
MANUFACTURER MODEL #:	
RATED DISCHARGE (gpm):	
DESIGN DISCHARGE RATE (gpm):	
SUCTION LIFT/COLUMN HT (ft):	
TOTAL DYNAMIC HEAD (ft):	
% PUMP EFFICIENCY:	
BRAKE HORSE POWER (hp):	
POWER SOURCE:	

GAL/HR: ______ KW/HR/HR: ______

COST/HOUR RUN TIME (base on current energy rates):

DIESEL ______ ELECTRIC ______ GASOLINE ______

OPERATE PUMP AT: ______ **psi** ______ **gpm**

PESSURE RANGE WITHIN ZONE: ______ **psi**

FERTIGATION AND CHEMIGATION: YES ☐ NO ☐

TYPE OF INJECTOR: ______

RATE OF INJECTION (gph): ______

TYPE OF BACKFLOW PREVENTION DEVICE: ______

			THRUST BLOCK AREA				
PIPE SIZE	**FITTING**	**PRESSURE**	**W (in)**	**L (in)**	**H (in)**		

NOTE: FOR PC EMITTERS 80% OR MORE PRESSURE VARIATION WILL RESULT IN 20% FLOW VARIATION, (+/-10%). REFER TO MANUFACTURER SHEETS.

- ☐ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.
- ☐ SYSTEM MEETS WITH RECOMMENDED CHANGES TO IMPROVE EFFICIENCY.
- ☐ SYSTEM DOES NOT MEET NRCS STANDARDS AND SPECS. REFER TO ATTACHED SHEET FOR RECOMMENDED DESIGN CHANGES

MICROSPRINKLER IRRIGATION DESIGN

COOPERATOR: DATE:
COUNTY: TWP:
CHECKED: APPROVED:

CROP DATA

IRRIGATED ACRES:	ac
TYPE:	
ROOT ZONE DEPTH:	in
ROW SPACING:	ft
SPACING BETWEEN PLANTS:	ft
CANOPY DIAMETER:	ft
SURFACE AREA (sqft):	ft^2
CANOPY COVER (sqft):	ft^2
CANOPY COEFFICENT (Kc2):	
% FOLIAGE COVERAGE:	%
ETO:	
CROP COEFFICENT (Kc1):	
ETC:	
PEAK PLANT WATER USE (per day):	gal
GROSS IRRIGATION REQUIREMENTS (per day):	gal

SOIL DATA

SOIL TEXTURE:		
SERIES:		
APPLICATION RATE:		$^{"}/_{hr}$
AVAILABLE WATER CAPACITY:		in
AMOUNT TO APPLY:		in
IRRIGATION FREQUENCY (no rain):		days
TOTAL HOURS OF IRRIGATION:		hr
MOISTURE TENSION (cb):		

DESIGN DATA

IRRGATION PIPE LINE TYPE AND RATING:		psi
LATERAL LINE: MANUFACTURER, ID, THICKNESS		
EMISSION DEVICE: TYPE AND MANUFACTURER		
FLOW RATE:	$^{g}/_{hr}$	
DESIGN PRESSURE:	psi	
RECOMMENDED PRESSURE RANGE:	psi	
MAXIMUM LATERAL LENGTH:	ft	
MICROSPRINKLER SPACING:	ft	
WETTED DIAMETER/MICROSPRINKLER:	ft	
WETTED AREA/TREE:	ft^2	
% ROOT ZONE AREA WETTED:	%	
GAL/MINUTE/ACRE	$^{gpm}/_{ac}$	
APPLICATION RATE:	$^{in}/_{hr}$	
DESIGN AREA TO BE IRRIGATED:		
NET APPLICATION RATE (ROOT ZONE):	$^{in}/_{hr}$	
DAILY HOURS OF IRRIGATION:	$^{hr}/_{day}$	

MINIMUM CAPACITY REQUIRED FOR IRRIGATED ACRES:	gpm

FRICTION LOSSES

TYPE OF MAINLINE:		TOTAL FLOW (gpm)	LENGTH (ft)	FRICTION LOSSES (psi per 100')	CUM. LOSSES (psi)
MAINLINE (in)					
SUBMAIN (in)					
LATERAL					
FILTER					
HYDROCYCLONE					
STATIC (outside zone)					
STATIC (inside zone)					
FITTING (%)					
TOTAL					
TOTAL PRESSURE LOSSES IN ZONE					
END LATERAL PRESSURE					
REGULATE ZONE AT					
MINIMUM OPERATED PRESSURE AT PUMP					

PUMP DATA

TYPE:
MANUFACTURER MODEL #:
RATED DISCHARGE (gpm):
DESIGN DISCHARGE RATE (gpm):
SUCTION LIFT/COLUMN HT (ft):
TOTAL DYNAMIC HEAD (ft):
% PUMP EFFICIENCY:
BRAKE HORSE POWER (hp):
POWER SOURCE:

GAL/HR: KW/HR/HR:
COST/HOUR RUN TIME (base on current energy rates):
DIESEL ELECTRIC GASOLINE

OPERATE PUMP AT: **psi** **gpm**

PESSURE RANGE WITHIN ZONE: **psi**
FERTIGATION AND CHEMIGATION: YES ☐ NO ☐
TYPE OF INJECTOR:
RATE OF INJECTION (gph):
TYPE OF BACKFLOW PREVENTION DEVICE:

PIPE SIZE	FITTING	PRESSURE	THRUST BLOCK AREA W (in)	L (in)	H (in)		

NOTE: FOR PC EMITTERS 80% OR MORE PRESSURE VARIATION WILL RESULT IN 20% FLOW VARIATION, (+/-10%). REFER TO MANUFACTURER SHEETS.

☐ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.
☐ SYSTEM MEETS WITH RECOMMENDED CHANGES TO IMPROVE EFFICIENCY.
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SPRINKLER IRRIGATION DESIGN

COOPERATOR: DATE:
COUNTY: TWP:
CHECKED: APPROVED:

CROP DATA

IRRIGATED ACRES:	ac
TYPE:	
ROOT ZONE DEPTH:	in
ROW SPACING:	ft
SPACING BETWEEN PLANTS:	ft
ETO (avg. N.J. peak ET rate):	
CROP COEFFICENT (Kc1):	
ETC:	in/day

SOIL DATA

SOIL TEXTURE:		
SOIL SERIES:		
MAXIMUM APPLICATION RATE:		"/hr
AVAILABLE WATER CAPACITY:		in
AMOUNT TO APPLY:		in
IRRIGATION FREQUENCY (no rain):		days
TOTAL HOURS OF IRRIGATION:		hr
MOISTURE TENSION (cb):		

DESIGN DATA

IRRGATION PIPE LINE TYPE AND RATING:		psi
TYPE OF SPRINKLER:		
MANUFACTURER MODEL:		
DESIGN FLOW RATE:	gpm	
DESIGN PRESSURE:	psi	
WETTED DIAMETER:	ft	
SPRINKLER SPACING:	ft	
LATERAL SPACING:	ft	
GAL/MINUTE/ACRE	gpm/ac	
DESIGN APPLICATION RATE:	in/hr	
POTENTIAL SYSTEM EFFICIENCY:		
NET IRRIGATION REQUIRED PER DAY:	in/day	
GROSS IRRIGATION PER DAY:	in/day	
DAILY TIME OF IRRIGATION:	hr/day	

MINIMUM CAPACITY REQUIRED FOR IRRIGATED ACRES:	gpm
PUMPING CAPACITY AVAILABLE:	gpm

FRICTION LOSSES

TYPE OF MAINLINE:

		TOTAL FLOW (gpm)	LENGTH (ft)	FRICTION LOSSES (psi per 100')	CUM. LOSSES (psi)
MAINLINE (in)					
SUBMAIN (in)					
LATERAL					
FILTER					
HYDROCYCLONE					
STATIC (outside zone)					
STATIC (inside zone)					
FITTING (%)					
TOTAL					

PUMP DATA

TYPE:	
MANUFACTURER MODEL #:	
RATED DISCHARGE (gpm):	gpm
DESIGN DISCHARGE RATE (gpm):	gpm
SUCTION LIFT/COLUMN HT (ft):	
TOTAL DYNAMIC HEAD (ft):	
% PUMP EFFICIENCY:	
BRAKE HORSE POWER (hp):	
POWER SOURCE:	

GAL/HR: ______ KW/HR/HR: ______

COST/HOUR RUN TIME (base on current energy rates):

DIESEL ______ ELECTRIC ______ GASOLINE ______

OPERATE PUMP AT: ______ psi ______ gpm

PIPE SIZE	FITTING	PRESSURE	THRUST BLOCK AREA W (in)	L (in)	H (in)		

☐ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.
☐ SYSTEM MEETS WITH RECOMMENDED CHANGES TO IMPROVE EFFICIENCY.
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HOOPHOUSE SPRINKLER IRRIGATION DESIGN

COOPERATOR: DATE:
COUNTY: TWP:
CHECKED: APPROVED:

CROP DATA

IRRIGATED ACRES:	ac
TYPE:	
ROOT ZONE DEPTH:	in
ETO (avg. N.J. peak ET rate):	
CROP COEFFICENT (Kc1):	
ETC:	in/day

SOIL DATA

CONTAINER

SOIL TEXTURE:	
AVAILABLE WATER CAPACITY:	in
MOISTURE TENSION (cb):	cb

FIELD

SOIL SERIES:	
SOIL TEXTURE:	
APPLICATION RATE:	"/hr

DESIGN DATA

IRRGATION PIPE LINE TYPE AND RATING:		psi
TYPE OF SPRINKLER:		
MANUFACTURER MODEL:		
DESIGN FLOW RATE:	gpm	
DESIGN PRESSURE:	psi	
WETTED DIAMETER:	ft	
SPRINKLER SPACING:	ft	ft
GAL/MINUTE/ACRE	gpm/ac	
APPLICATION RATE:	in/hr	
POTENTIAL SYSTEM EFFICIENCY:		
NET IRRIGATION REQUIRED PER DAY:	in/day	
GROSS IRRIGATION PER DAY:	in/day	
DAILY TIME OF IRRIGATION:	min/day	
IRRIGATION FREQUENCY:	day	
TOTAL HOURS OF IRRIGATION:	hr	
GROSS AMOUNT TO APPLY:	in	

MINIMUM CAPACITY REQUIRED FOR IRRIGATED ACRES:	gpm
PUMPING CAPACITY AVAILABLE:	gpm

FRICTION LOSSES

TYPE OF MAINLINE:		TOTAL FLOW (gpm)	LENGTH (ft)	FRICTION LOSSES (psi per 100')	CUM. LOSSES (psi)
MAINLINE (in)					
SUBMAIN (in)					
LATERAL					
FILTER					
HYDROCYCLONE					
STATIC (outside zone)					
STATIC (inside zone)					
FITTING (%)					

PUMP DATA

TYPE:
MANUFACTURER MODEL #:
RATED DISCHARGE (gpm): gpm
DESIGN DISCHARGE RATE (gpm): gpm
SUCTION LIFT/COLUMN HT (ft): ft
TOTAL DYNAMIC HEAD (ft): ft
% PUMP EFFICIENCY:
BRAKE HORSE POWER (hp):
POWER SOURCE:

GAL/HR: KW/HR/HR:
COST/HOUR RUN TIME (base on current energy rates):
DIESEL ELECTRIC GASOLINE

OPERATE PUMP AT: psi gpm

FERTIGATION AND CHEMIGATION: YES ☐ NO ☐
TYPE OF INJECTOR:
RATE OF INJECTION (gph):
TYPE OF BACKFLOW PREVENTION DEVICE:

TAIL WATER RECOVERY SYSTEM: RECYCLING: YES ☐ NO ☑

PUMP BACK WATER TREATMENT: CLORINATION: ☐
IONIZATION: ☐

PIPE SIZE	FITTING	PRESSURE	THRUST BLOCK AREA W (in)	L (in)	H (in)		

☐ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.
☐ SYSTEM MEETS WITH RECOMMENDED CHANGES TO IMPROVE EFFICIENCY.
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CENTER PIVOT IRRIGATION DESIGN

COOPERATOR: DATE:
COUNTY: TWP:
CHECKED: APPROVED:

CROP DATA

TOTAL ACRES:	ac
AREA IRRIGATED BY CENTER PIVOT WETTED RADIUS:	ac
CROP TYPE:	
ROOT ZONE DEPTH:	in
ETO:	
CROP COEFFICIENT (Kc1):	
ETC:	in/day

SOIL DATA

SOIL TEXTURE:	
SERIES:	
INTAKE FAMILY:	
RESIDUE:	lb/ac
LAND SLOPE:	%
AVAILABLE WATER CAPACITY:	in
MOISTURE TENSION (50% DEPLETION):	cb

DESIGN DATA

IRRIGATION PIPE LINE TYPE AND RATING:		psi
PIVOT MAKE AND MODEL:		
SPRINKLER TYPE AND MODEL:		
SPRINKLER SPACING ALONG LATERAL:	ft	
SYSTEM LENGTH:	ft	
END GUN MODEL:		
END GUN NOZZLE SIZE:	in	
END GUN FLOW RATE:	gpm	
END GUN PRESSURE:	psi	
END GUN RADIUS:	ft	
NUMBER OF TOWERS:		
DESIGN FLOW RATE:	gpm	
DESIGN PRESSURE AT PIVOT:	psi	
CENTER PIVOT WETTED RADIUS:	ft	
DISTANCE FROM CENTER PIVOT TO OUTER DRIVE WHEEL:	ft	
WETTED DIAMETER OF LARGEST LATERAL NOZZLE:	ft	
NOZZLE PRESSURE WITH REGULATOR:	psi low and medium flow	
SYSTEM EFFICIENCY:	%	
MAXIMUM IRRIGATION APPLICATION PER REVOLUTION:	in	
GROSS APPLICATION PER DAY:	in	
TIME TO IRRIGATE CENTER PIVOT AREA (one revolution):	days	hrs
GPM/ACRE:	gpm/ac	
MINIMUM GROSS IRRIGATION REQUIREMENT (gpm/ac):	gpm/ac	
MAXIMUM ALLOWABLE APPLICATION RATE:	in/hr	
DESIGN APPLICATION RATE:	in/hr	
CHECK SPRINKLER DESIGN FLOW RATE:	gpm	
CHECK END GUN FLOW RATE:	gpm	

MINIMUM CAPACITY REQUIRED FOR TOTAL ACRES:	gpm	MINIMUM CAPACITY REQUIRED FOR CENTER PIVOT ACRES:	gpm
TOTAL PUMPING CAPACITY AVAILABLE:	gpm	CENTER PIVOT DESIGN CAPACITY:	gpm

FRICTION LOSSES

TYPE OF MAINLINE:

		TOTAL FLOW (gpm)	LENGTH (ft)	FRICTION LOSSES (psi per 100')	CUM. LOSSES (psi)
MAINLINE (in)					
PIVOT LATERAL					
FILTER					

PUMP DATA

TYPE:
MANUFACTURER MODEL #:
RATED DISCHARGE (gpm):
DESIGN DISCHARGE RATE (gpm):
SUCTION LIFT/PUMPING DEPTH (ft):
TOTAL DYNAMIC HEAD REQUIRED (ft):
TOTAL DYNAMIC HEAD AVAILABLE (ft):
% PUMP EFFICIENCY:
BRAKE HORSE POWER (hp):
POWER SOURCE:

GAL/HR: KW/HR/HR:
COST/HOUR RUN TIME (base on current energy rates):
DIESEL ELECTRIC GASOLINE

PUMP OPERATING PRESSURE: psi

PRESSURE REDUCING VALVE NEEDED: ☐ YES ☐ NO

PRV (psi): psi

BOOSTER PUMP:

LINE PRESSURE AT END OF LATERAL: psi
GUN HOSE LOSSES: psi
BOOSTER PUMP (psi): psi
BRAKE HORSE POWER (hp): hp

			THRUST BLOCK AREA				
PIPE SIZE	FITTING	PRESSURE	W (in)	L (in)	H (in)		

☐ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.
☐ SYSTEM MEETS WITH RECOMMENDED CHANGES TO IMPROVE EFFICIENCY.
☐ SYSTEM DOES NOT MEET NRCS STANDARDS AND SPECS. REFER TO ATTACHED SHEET FOR RECOMMENDED DESIGN CHANGES

LINEAR MOVE IRRIGATION DESIGN

COOPERATOR: DATE:
COUNTY: TWP:
CHECKED: APPROVED:

CROP DATA

TOTAL ACRES:	ac
DISTANCE TRAVELED BY LINEAR MOVE:	ft
AREA IRRIGATED BY LINEAR MOVE SYSTEM:	ac
CROP TYPE:	
ROOT ZONE DEPTH:	in
ETO:	
CROP COEFFICIENT (Kc1):	
ETC:	in/day

SOIL DATA

SOIL TEXTURE:	
SERIES:	
INTAKE FAMILY:	
RESIDUE:	lb/ac
LAND SLOPE:	%
AVAILABLE WATER CAPACITY:	in
MOISTURE TENSION (50% DEPLETION):	cb

DESIGN DATA

IRRIGATION PIPE LINE TYPE AND RATING:		psi
LINEAR MOVE MAKE AND MODEL:		
SPRINKLER TYPE AND MODEL:		
SPRINKLER SPACING ALONG LATERAL:	ft	
SYSTEM LENGTH:	ft	
END GUN MODEL:		
END GUN NOZZLE SIZE:	in	
END GUN FLOW RATE:	gpm	
END GUN PRESSURE:	psi	
END GUN RADIUS:	ft	
NUMBER OF TOWERS:		
DESIGN FLOW RATE:	gpm	
DESIGN PRESSURE AT PIVOT:	psi	
LINEAR MOVE WETTED LENGTH:	ft	
DISTANCE FROM CENTER PIVOT TO OUTER DRIVE WHEEL:	ft	
WETTED DIAMETER OF SPRINKLER NOZZLE:	ft	
NOZZLE PRESSURE WITH REGULATOR:	psi low and medium flow	
SYSTEM EFFICIENCY:	%	
MAXIMUM IRRIGATION APPLICATION PER REVOLUTION:	in	
GROSS APPLICATION PER DAY:	in	
TIME TO IRRIGATE LINERA MOVE AREA (one pass):	days	hrs
GPM/ACRE:	gpm/ac	
MINIMUM GROSS IRRIGATION REQUIREMENT (gpm/ac):	gpm/ac	
MAXIMUM ALLOWABLE APPLICATION RATE:	in/hr	
DESIGN APPLICATION RATE:	in/hr	
CHECK SPRINKLER DESIGN FLOW RATE:	gpm	

MINIMUM CAPACITY REQUIRED FOR IRRIGATED ACRES:	gpm
PUMPING CAPACITY AVAILABLE:	gpm

FRICTION LOSSES

TYPE OF MAINLINE:		TOTAL FLOW (gpm)	LENGTH (ft)	FRICTION LOSSES (psi per 100')	CUM. LOSSES (psi)
MAINLINE (in)					

PUMP DATA

TYPE:	
MANUFACTURER MODEL #:	
RATED DISCHARGE (gpm):	
DESIGN DISCHARGE RATE (gpm):	
SUCTION LIFT/PUMPING DEPTH (ft):	
TOTAL DYNAMIC HEAD REQUIRED (ft):	
TOTAL DYNAMIC HEAD AVAILABLE (ft):	
% PUMP EFFICIENCY:	
BRAKE HORSE POWER (hp):	
POWER SOURCE:	

GAL/HR: ______ KW/HR/HR: ______

COST/HOUR RUN TIME (base on current energy rates):

DIESEL ______ ELECTRIC ______ GASOLINE ______

PUMP OPERATING PRESSURE: ______ **psi**

PRESSURE REDUCING VALVE NEEDED: ☐ YES ☐ NO

PRV (psi): ______ psi

BOOSTER PUMP:

LINE PRESSURE AT END OF LATERAL:	**psi**
GUN HOSE LOSSES:	**psi**
BOOSTER PUMP (psi):	**psi**
BRAKE HORSE POWER (hp):	**hp**

			THRUST BLOCK AREA				
PIPE SIZE	**FITTING**	**PRESSURE**	**W (in)**	**L (in)**	**H (in)**		

☐ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.
☐ SYSTEM MEETS WITH RECOMMENDED CHANGES TO IMPROVE EFFICIENCY.
☐ SYSTEM DOES NOT MEET NRCS STANDARDS AND SPECS. REFER TO ATTACHED SHEET FOR RECOMMENDED DESIGN CHANGES

TRAVELING GUN IRRIGATION DESIGN

COOPERATOR: DATE:
COUNTY: TWP:
CHECKED: APPROVED:

CROP DATA

IRRIGATED ACRES:	ac
TYPE:	
ROOT ZONE DEPTH:	in
ETO (avg. N.J. peak ET rate):	
CROP COEFFICENT (Kc1):	
ETC:	

SOIL DATA

SOIL TEXTURE:		
SOIL SERIES:		
MAXIMUM APPLICATION RATE:		"/hr
AVAILABLE WATER CAPACITY:		in
AMOUNT TO APPLY:		in
MOISTURE TENSION (cb):		

DESIGN DATA

IRRGATION PIPE LINE TYPE AND RATING:		psi
TYPE/SIZE OF NOZZLE:		
MANUFACTURER MODEL:		
TRAVELER MODEL:		
HOSE DIAMETER AND LENGTH:	in	ft
DESIGN FLOW RATE:	gpm	
DESIGN PRESSURE:	psi	
WETTED DIAMETER:	ft	
TOWPATH (RISER) SPACING:	ft	
SPEED OF TRAVELER:	ft/min	
DESIGN APPLICATION RATE:	in/hr	
POTENTIAL SYSTEM EFFICIENCY:		
GROSS IRRIGATION:	in	
NET IRRIGATION APPLIED:	in	
IRRIGATION FREQUENCY (no rain):	days	

MINIMUM CAPACITY REQUIRED FOR IRRIGATED ACRES:	gpm
PUMPING CAPACITY AVAILABLE:	gpm

FRICTION LOSSES

TYPE OF MAINLINE:		TOTAL FLOW (gpm)	LENGTH (ft)	FRICTION LOSSES (psi per 100')	CUM. LOSSES (psi)
MAINLINE (in)					
SUBMAIN (in)					
TRAVELER HOSE ID					
TURBINE					
FILTER					
SAND SEPARATOR					
STATIC					
FITTING (%)					

PUMP DATA

TYPE:	
MANUFACTURER MODEL #:	
RATED DISCHARGE (gpm):	**gpm**
DESIGN DISCHARGE RATE (gpm):	**gpm**
SUCTION LIFT/COLUMN HT (ft):	
TOTAL DYNAMIC HEAD (ft):	
% PUMP EFFICIENCY:	
BRAKE HORSE POWER (hp):	
POWER SOURCE:	

GAL/HR: ______ KW/HR/HR: ______

COST/HOUR RUN TIME (base on current energy rates):

DIESEL ______ ELECTRIC ______ GASOLINE ______

OPERATE PUMP AT: ______ **psi** ______ **gpm**

PIPE SIZE	**FITTING**	**PRESSURE**	**THRUST BLOCK AREA** W (in)	L (in)	H (in)		

☐ SYSTEM MEETS NRCS STANDARDS AND SPECIFICATIONS.
☐ SYSTEM MEETS WITH RECOMMENDED CHANGES TO IMPROVE EFFICIENCY.
☐ SYSTEM DOES NOT MEET NRCS STANDARDS AND SPECS. REFER TO ATTACHED SHEET FOR RECOMMENDED DESIGN CHANGES

IWM DATA SHEET

Month ________________ Field ______________________________

Soil Texture ________________ Available water _________ inches

Allowable Depletion _________ inches

Irrigate At ________ Irrigation Rate of Application __________________

Date	Site #1 Sensor Readings (CB)		Site #2 Sensor Readings (CB)		Rainfall (inches)	Run Time (hours)	Irrigation (inches)	ET (inches)	Moisture Balance	Fertigation (hours)
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										
31										

Total For Month: ET ________________ Rainfall ____________________ Irrigation ____________________

Weather Station- ____

Chapter 16

Special Use Tables, Charts, and Conversions

Contents

NJ Chapter 16 Special Use Tables, Charts, and Conversions

UNITS OF WATER MEASURMENT

1 gal. = 8.34 lbs. = 0.1337 cu. ft. = 231 cu. in.

1 cu. ft. (7.48)(8.34) = 62.4 lbs.

1 acre-in. 27,154 gal. = 3,630 cu. ft.

1 acre-ft. 325,828 (326,000) gal. = 34,560 cu. ft.

1 cu. ft. per sec. = 449 (450) gal. per min. = 0.9917 (1.01) acre-in. per hr.

1 acre-in. per hr. = 453 (450) gpm

1 acre-ft. per day = 226 (225) gpm

1,000,000 gal. per day = 695 gpm = 1.55 cu. ft. per sec. = 3.08 ac. ft./day

1 ft. of water (head) 0.433 psi

1 psi = 2.31 ft. of water (head)

METRIC SYSTEM CONVERSIONS

Measures of Length

10 millimeters = 1 centimeter 0.3937 in.

10 centimeters (cm) = 1 decimeter 3.937 in.

10 decimeters (dm) = 1 meter 39.37 in.

10 meters (m) = 1 decameter = 393.7 in.

10 decameters (dkm) = 1 hectometer 329 ft. 1 in.

10 hectometers (hm) = 1 kilometer = 0.6214 mi.

10 kilometers (km) = 1 myriameter (mym) = 6.214 mi.

Land Measures

1 sq. meter (m^2) = 1 centiare = 1550 sq. in.

100 centiares (ca) or 100 m^2 = 1 are = 119.6 sq. yd.

100 ares (a) or 10,000 m^2 = 1 hectare (ha) = 2,471 acres

1 sq. kilometer (km) = 1,000,000 sq. meters = 0.3861 sq. mi.

Measures of Capacity
The standard unit of capacity is the liter, equal to cubic decimeter or 0.9081 dry quart or 1.0567 liquid quarts.

10 milliliters (ml) = 1 centileter = 0.338 fl. oz.

10 centileters (cl) = 1 decileter = 6.1025 cu. in.

10 deciliters (dl) = 1 liter = 0.9081 dry qt.

10 liters (1) = 1 decaliter = 0.284 bu. or 2.64 gal.

10 decaliters (dkl) = 1 hectoliter = 2.838 bu. or 26.418 gal.

10 hectoliters (hl) = 1 kiloliter = 35.315 cu. ft. or 264.18 gal.

Metric Equivalents of Common Units
Inch = 2.54
Foot = 0.308 m
Yard = 0.9144m
Rod = 5.029 m
Mile = 1.6093 km
sq. inch = 6.452 cm2
sq. foot = 0.0929 m2
sq. yard = 0.8361 m2
acre = 0.4047 ha
sq. mile = 259 ha or 2.590 km2
cu. Inch = 16.387 cm3
cu. Foot = 0.0283 m3
cu. Yard = 0.7646 m3
liquid qt. = 0.9463 L
dry qt. = 1.1012 L
gallon = 3.7853 L
bushel = 35.238 L
oz. av. = 0.4536 kg
oz. troy = 31.1035 g
lb. troy = 0.3732 kg

SPEEDY MOISTURE TESTER CONVERSION CHART

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

Chapter 17 Glossary and References

NJ Chapter 17 Glossary and References

Advance time (1) Time required for a given surface irrigation stream of water to move from the upper end of a field to the lower end.
(2) Time required for a given surface irrigation stream to move from one point in the field to another.

Algicide Any substance that will kill or control algae growth.

Alkali soil See sodic soil.

Allowable depletion That part of soil moisture stored in the plant root zone managed for use by plants, usually expressed as equivalent depth of water in acre inches per acre, or inches.

Alternate set irrigation A method of managing irrigation whereby, at every other irrigation, alternate furrows are irrigated or sprinklers are placed midway between theirlocations during the previous irrigation.

Application efficiency (Ea) The ratio of the average depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percentage. Also referred to as AE.

Application efficiency low half The ratio of the average of the low one-half of measurements of irrigation (Eh) water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percentage. Also called AELH. Used as an indication for uniformity of application.

Application efficiency low The ratio of the average of the lowest one-fourth of measurements of quarter (Eq) irrigation water infiltrated to the average depth of irrigation water applied, expressed as a percentage. Also called AELQ. Used as an indication for uniformity of application.

Application rate, sprinkler The rate at which water is applied to a given area by a sprinkler system. application rate Usually expressed in inches per hour.

Application time, set time The amount of time that water is applied to an irrigation set.

Arid climate Climate characterized by low rainfall and high evaporation potential. A region is usually considered as arid when precipitation averages less than 10 inches (250 mm) per year.

Available soil water The difference between actual water content of a soil and the water held by that soil at the permanent wilting point.

Available water capacity (AWC) The portion of water in a soil that can be readily absorbed by plant roots of most crops, expressed in inches per inch, inches per foot, or total inches for a specific soil depth. It is the amount of water stored in the soil between field capacity (FC) and permanent wilting point (WP). It is typically adjusted (AWHC).

Average annual precipitation The long-term or historic (generally 30 years or more) arithmetic mean of precipitation (rain, snow, dew) received by an area.

Average daily peak use rate Calculated or measured water used by plants in 1 day through evapotranspiration, expressed as inches per day.

Backilow prevention device Safety device that prevents the flow of water from the water distribution system back to the water source.

Basic intake rate Rate at which water percolates into soil after infiltration has decreased to a nearly constant value.

Basin irrigation Surface irrigation by flooding areas of level land surrounded by dikes. Generally used interchangeably with level border irrigation. In some areas level borders have tallwater runoff. If used in high rainfall areas, storm runoff facilities are necessary.

Blaney-Criddle Method An air temperature based method to estimate crop evapotranspiration.

Border irrigation Surface irrigation by flooding strips of land, rectangular in shape, usually level perpendicular to the irrigation slope, surrounded by dikes. Water is applied at a rate sufficient to move it down the strip in a uniform sheet. Border strips having no down field slope are referred to as level border systems. Border systems constructed on terraced lands are commonly referred to as benched borders.

Broad-crested weir Any of a group of thick-crested overspill weirs used for flow measurements in open channels. Some broad-crested weirs may have flow transitions, roundings, or plane surface ramps on the upstream side. Thin versions without transitions approach the behavior of sharp-crested weirs. Thick versions with transitions approach the behavior of long-throated flumes. Broad-crested weirs typically operate with very little head loss.

Bubbler irrigation Micro irrigation application of water to flood the soil surface using a small stream or fountain. The discharge rates for point-source bubbler emitters are greater than for drip or subsurface emitters, but generally less than 1 gallon per minute (225 L/h). A small basin is usually required to contain or control the water.

Bulk density Mass of dry soil per unit volume, determined by drying to constant weight at 105 °C, usually expressed as gmlcc or lb/ft3. Rock fragments 2 mm or larger are usually excluded or corrected for after measurement.

Cablegation A semiautomatic furrow irrigation system where a gated pipe is used to deliver water to each furrow. A continuous moving plug is attached to a speed control device with a small cable. The moving plug allows flow out of newly passed gates. As the plug moves downstream, the water level drops in upstream gates thereby shutting off flows.

Capillary water Water held in the capillary or small pores of the soil, usually with soil water pressure (tension) greater than 1/3 bar. Capillary water can move in any direction.

Carryover soil moisture Moisture stored in the soil within the root zone during the winter, at times when the crop is dormant, or before the crop is planted. This moisture is available to help meet water needs of the next crop to be grown.

Cation exchange capacity (CEC) The sum of exchangeable cations (usually Ca, Mg, K, Na, Al, H) that the soil constituent or other material can adsorb at a specific pH, usually expressed in centimoles of charge per Kg of exchanger (cmo]IKg), or milli equivalents per 100 grams of soil at neutrality (pH = 7.0), meq/lOOg.

Check, check structure Structure to control water depth in a canal, lateral, ditch, or irrigated field.

Chemigation Application of chemicals to crops through an irrigation system by mixing them with irrigation water.

Christiansen's uniformity coefficient (CU) A measure of the uniformity of irrigation water application. The average depth of irrigation water infiltrated minus the average absolute deviation from this depth, all divided by the average depth infiltrated. Also called coefficient of uniformity. Typically used with sprinkle irrigation systems.

Cipolletti weir A sharp-crested trapezoidal weir with sides inclining outwardly at a slope of 1 horizontal to 4 vertical.

Compensating emitter Micro irrigation system emitters designed to discharge water at a near constant rate over a wide range of lateral line pressures.

Consumptive use See Evapotranspiration and Crop evapotranspiration.

Continuous flushing emitter Micro irrigation system emitters designed to continuously permit passage of large solid particles while operating at a trickle or drip flow, thus reducing filtration requirements.

Contracted weir A measuring weir that is shorter than the width of the channel and is therefore said to have side or end contractions. Sometimes called a sharpcrested weir.

Control structure Water regulating structure, usually for open channel flow conditions.

Conveyance efficiency (Ec) The ratio of the water delivered to the total water diverted or pumped into an open channel or pipeline at the upstream end, expressed as a percentage.

Conveyance loss Loss of water from a channel or pipe during transport, including losses resulting from seepage, leakage, evaporation, and transpiration by plants growing in or near the channel.

Corrugation irrigation A surface irrigation system where small ditches, channels, or furrows are used to guide water downslope. Can be used in combination with graded border systems to provide more uniform flow down the border strip.

Crop coefficient (Kc) A factor used to modify potential evapotranspiration:
(1) Ratio between crop evapotranspiration (ETa) and the reference crop (ET_0) when crop is grown in large fields under optimum growing conditions, or ETc = K~ times ET_0.
(2) The ratio of the actual crop evapotranspiration to its potential evapotranspiration.

Crop evapotranspiration (ETe) The amount of water used by the crop in transpiration and building of plant tissue, and that evaporated from adjacent soil or intercepted by plant foliage. It is expressed as depth in inches or as volume in acre inches per acre. It can be daily, peak, design, monthly, or seasonal. Sometimes referred to as consumptive use (CU).

Crop growth stages Periods of like plant function during the growing season. Usually four or more periods are identified:
Initial—Between planting or when growth begins and approximately 10 percent ground cover.
Crop development—Between about 10 percent ground cover and 70 or 80 percent ground cover.
Mid season—From 70 or 80 percent ground cover to beginning of maturity. Late—From beginning of maturity to harvest.

Crop rooting depth Crop rooting depth is typically taken as the soil depth containing 80 percent of plant roots, measured in feet or inches.

Crop water stress index (CWSI) An index of moisture in a plant compared to a fully watered plant, measured and calculated by a CWSI instrument. Relative humidity, solar radiation, ambient air temperature, and plant canopy temperature are measured. Improperly called an infrared thermometer (plant canopy temperature is measured by infrared aerial photography).

Crop water use Calculated or measured water used by plants, expressed in inches per day. Same as ET~ except it is expressed as daily use only.

Cumulative intake The depth of water absorbed by soil from the time of initial water application to the specified elapsed time.

Cutback irrigation The reduction of the furrow or border inflow stream after water has advanced partly or completely through the field to reduce runoff and improve uniformity of application.

Cutback stream Reducing surface irrigation inflow stream size (usually a half or a third) when a specified time period has elapsed or when water has advanced a designated distance down the furrow, corrugation, or border.

Cutthroat flume Open-channel waterfiow measuring device that is part of a group of shortthroated flumes that control discharge by achieving critical flow with curving streamlines through contraction. The flume is rectangular in cross section, has two main parts resembling a Parshall Flume with the contracted throat removed or cut out (hence its name), and has a flat floor throughout. Calibrations depend on laboratory ratings.

Cycle time The length of water application periods, typically used with surge irrigation.

Deep percolation (DP) Water that moves downward through the soil profile below the plant root zone and is not available for plant use. A major source of ground water pollution in some areas.

Deficit irrigation An irrigation water management alternative where the soil in the plant root zone is not refilled to field capacity in all or part of the field.

Delivery box Water control structure for diverting water from a canal to a farm unit often including a measuring device. Also called delivery site, delivery facility, and turnout.

Demand irrigation delivery Irrigation water delivery procedure where each irrigator may request irrigation water in the amount needed and at the time desired.

Depth of irrigation (1) Depth of water applied, measured in acre inches per acre.
(2) Depth of soil affected by an irrigation event.

Distribution uniformity (DU) The measure of the uniformity of irrigation water distribution over a field. NRCS typically uses DU of low one-quarter. DU of low one-quarter is the ratio of the average of the lowest one-fourth of measurements of irrigation water infiltrated to the average depth of irrigation water infiltrated, expressed as a decimal. Each value measured represents an equal area.

Distribution system A network of open canals or pipelines to distribute irrigation water at a specific design rate to multiple outlets on a farm or in a community.

Drip irrigation A micro irrigation application system wherein water is applied to the soil surface as drops or small streams through emitters. Discharge rates are generally less than 2 gallons per hour (8 L/h) for single outlet emitters and 3 gallons per hour (12 h/h) per meter for line source emitters.

Effective precipitation (Pe) The portion of precipitation that is available to meet crop evapotranspiration. It does not include precipitation that is lost to runoff, deep percolation, or evaporation before the crop can use it.

Effective rooting depth The depth from which roots extract water. The effective rooting depth is generally the depth from which the crop is currently capable of extracting soil water. However, it may also be expressed as the depth from which the crop can extract water when mature or the depth from which a future crop can extract soil water. Maximum effective root depth depends on the rooting capability of the plant, soil profile characteristics, and moisture 1~ve1s in t.h~ soil urofile.

Electrical conductivity (EC) A measure of the ability of the soil water to transfer an electrical charge. Used as an indicator for the estimation of salt concentration, measured in mmhos/cm (dS/m), at 77 °F (25 °C).
ECe = Electrical conductivity of soil water extract.
EC_1 = Electrical conductivity of irrigation water.
ECa~ = Electrical conductivity of applied water.

Electrical resistance blocks A block made up of various material containing electrical contact wires that is placed in the soils at selected depths to measure soil moisture content. Electrical resistance, as affected by moisture in the block, is read with a meter.

Emitter A small micro irrigation dispensing device designed to dissipate pressure and discharge a small uniform flow or trickle of water at a constant discharge. Also called a dripper or trickler.
Compensating emitter—Designed to discharge water at a constant rate over a wide range of lateral line pressures.
Continuous flushing emitter—Designed to continuously permit passage of small solid particles while operating at a trickle or drip flow, thus reducing filter fineness requirements.
Flushing emitter—Designed to have a flushing flow of water to clear the discharge opening every time the system is turned on.
Line-source emitter—Water is discharged from closely spaced perforations, emitters, or a porous wall along the tubing.
Long-path emitter—Employs a long capillary sized tube or channel to dissipate pressure.
Multi-outlet emitter—Supplies water to two or more points through small diameter auxiliary tubing.
Orifice emitter—Employs a series of orifices to dissipate pressure.
Vortex emitter—Employs a vortex effect to dissipate pressure.

Energy gradient, energy grade line A plotted line relating total energy elevations along an open channel or conduit, typically a pressure pipeline. (See Hydraulic grade line).

Environmental control Controlling air temperature and humidity or soil moisture conditions to minimize effects of low and high air temperatures on crop quality and quantity.

Evaporation The physical process by which a liquid is transformed to the gaseous state, which in irrigation generally is restricted to the change of water from liquid to vapor. Occurs from plant leaf surface, ground surface, water surface, and sprinkler spray.

Evaporation Pan (1) A standard U.S. Weather Bureau Class A pan (48-inch diameter by 10-inch deep) used to estimate the reference crop evapotranspiration rate. Water levels are measured daily in the pan to determine the amount of evaporation.
(2) A pan or container placed at or about crop canopy height containing water. Water evaporated from the device is measured and adjusted by a coefficient to represent estimated crop water use during the period.

Evapotranspiration (ET) The combination of water transpired from vegetation and evaporated from soil and plant surfaces. Sometimes called consumptive use (CU).

Exchange capacity The total ionic charge of the absorption complex active in the adsorption of ions. See Cation exchange capacity (CEC).

Exchangeable cation A positively charged ion held on or near the surface of a solid particle by a negative surface charge of a colloid and which may be replaced by other positively charged ions in the soil solution.

Exchangeable sodium percentage The fraction of cation exchange capacity of a soil occupied by sodium ions,
(ESP) expressed as a percentage. Exchangeable sodium (meq/100 gram soil) divided by CEC (meq/100 gram soil) times 100. It is unreliable in soil containing soluble sodium silicate minerals or large amounts of sodium chloride.

Exchangeable sodium ratio (or percentage) The ratio of exchangeable sodium to all other exchangeable cations, expressed as meq/100 grams of soil or as a percentage.

FAO Blaney-Criddle Method A method to calculate grass reference crop evapotranspiration (ETc) based on long-term air temperature data, estimates for humidity, wind movement and sunshine duration, and a correction to ET~ downward for elevations above 1,000 meters above sea level.

Feel and appearance method A method to estimate soil moisture by observing and feeling a soil sample with the hand and fingers. With experience, this method can be accurate.

Field application duration (irrigation period) The elapsed time from the beginning of water application to the first irrigation set to the time at which water application is terminated on the last irrigation set of a field.

Field capacity The amount of water retained by a soil after it has been saturated and has drained freely by gravity. Can be expressed as inches, inches per inch, bars suction, or percent of total available water.

Field slope, grade The terms field slope and grade are interchangeable. Surface irrigation designers typically refer to elevation differences in the direction of water movement as the irrigation grade. Cross slope refers to the land grade perpendicular to the direction of irrigation.

Final infiltration rate See Basic intake rate.

Float valve A valve, actuated by a float, that automatically controls the flow of water.

Flood irrigation, wild flooding A surface irrigation system where water is applied to the soil surface without flow controls, such as furrows, borders (including dikes), or corrugations.

Flume (1) Open conduit for conveying water across obstructions.
(2) An entire canal or lateral elevated above natural ground, or an aqueduct.
(3) A specially calibrated structure for measuring open channel flows.

Flushing emitter A micro irrigation application device designed to have a flushing flow of water to clear the discharge opening each time the system is turned on.

Foot valve (1) A check valve used on the bottom of the suction pipe to retain the water in the pump when it is not in operation.
(2) A valve used to prevent backflow.

Free drainage Movement of water by gravitational forces through and below the plant root zone. This water is unavailable for plant use except while passing through the soil. (See Deep percolation.)

Frost protection Applying irrigation water to affect air temperature, humidity, and dew point to protect plant tissue from freezing. The primary source of heat (called heat of fusion) occurs when water turns to ice, thus protecting sensitive plant tissue. Wind machines and heating devices are also used.

Full irrigation Management of water applications to fully replace water used by plants over an entire field.

Fungicide Chemical pesticide that kills fungi or prevents them from causing diseases on plants.

Furrow (1) A trench or channel in the soil made by a tillage tool.
(2) Small channel for conveying irrigation water downslope across the field. Sometimes referred to as a rill or corrugation.

Furrow dike Small earth dike formed in a furrow to prevent water translocation. Typically used with LEPA and LPIC systems. Also used in nonirrigated fields to capture and infiltrate precipitation. Sometimes called reservoir tillage.

Furrow irrigation A surface irrigation system where water is supplied to small channels or furrows to guide water downslope and prevent cross flow. Called rill or corrugation irrigation in some areas.

Furrow stream The streamfiow in a furrow, corrugation, or rill.

Gates, slide gate A device used to control the flow of water to, from, or in a pipeline or open channel. It may be opened and closed by screw or slide action either manually or by electric, hydraulic, or pneumatic actuators. In open channels, gates slide on rails and are used to control drainage or irrigation water.

Gated pipe Portable pipe that has small gates installed at regular intervals along one side for distributing irrigation water to corrugations, furrows, or borders.

Gravimetric (ovendry) method A method of measuring total soil water content by sampling, weighing, and drying in a oven at 105 °C. Percent water, usually on a dry weight basis, is calculated.

Gravitational water Soil water that moves into, through, or out of the soil under the influence of gravity.

Gross irrigation Water actually applied, which may or may not be total irrigation water requirement; i.e., leaving storage in the soil for anticipated rainfall, harvest.

Gross irrigation requirement (Fg) The total irrigation requirement including net crop requirement plus any losses incurred in distributing and applying water and in operating the system. It is generally expressed as depth of water in acre inches per acre or inches

Gross irrigation system capacity Ability of an irrigation system to deliver the net required rate and volume of water necessary to meet crop water needs plus any losses during the application process. Crop water needs can include soil moisture storage for later plant use, leaching of toxic elements from the soil, air temperature modification, crop quality, and other plant needs.

Ground water Water occurring in the zone of saturation in an aquifer or soil.

Growing season The period, often the frost-free period, during which the climate is such that crops can be produced.

Gypsum block An electrical resistance block in which the material used to absorb water is gypsum. It is used to measure soil water content in non-saline soils.

Head ditch Ditch across the upper end of a field used for distributing water in surface irrigation.

Head gate Water control structure at the entrance to a conduit or canal.

Herbicide A chemical substance designed to kill or inhibit the growth of plants, especially weeds. Types include:
Contact—A herbicide designed to kill foliage on contact. *Non-selective—A* herbicide that destroys or prevents all plant growth.
Post-emergence—A herbicide designed to be applied after a crop is above the ground.
Pre-emergence—A herbicide designed to be applied before the crop emerges through the soil surface.
Selective—A herbicide that targets specific plants.

Humid climates Climate characterized by high rainfall and low evaporation potential. A region generally is considered as humid when precipitation averages more than 40 inches (1,000 mm) per year.

Hydrant An outlet, usually portable, used for connecting surface irrigation pipe to an alfalfa valve outlet.

Hydraulic conductivity The ability of a soil to transmit water flow through it by a unit hydraulic gradient. It is the coefficient k in Darcy's Law. Darcy's Law is used to express flux density (volume of water flowing through a unit cross-sectional area per unit of time). It is usually expressed in length per time (velocity) units, i.e., cm/s, ftld. In Darcy's Law, where V = ki, k is established for a gradient of one. Sometimes called permeability.

Hydraulic grade line (HGL) A plotted line relating operational energy elevations along an open channel or closed conduit. With open channel (non-pressure) flow, the HGL is at the water surface. The HGL is the elevation water would rise in an open stand at a given location along a pressure pipeline. (See Energy grade line).

Hydraulic ram Device that uses the energy of flowing water to lift a portion of the flow to a higher elevation or greater pressure.

Infiltration, infiltration rate The downward flow of water into the soil at the air-soil interface. Water enters the soil through pores, cracks, wormholes, decayed-root holes, and cavities introduced by tillage. The rate at which water enters soil is called intake rate or infiltration rate.

Infiltrometer A device for determining the intake rate of soil.
Ring infiltrometer—Consists of metal rings that are inserted (driven) into the soil surface and filled with water. The rate at which water enters the soil is recorded.
Sprinkler infiltrometer—Consists of a sprinkler head(s) that applies water to the soil surface at a range of rates of less-than to greater-than soil infiltration rates. Maximum infiltration rates are observed and recorded.
Flowing infiltrometer—Consists of an inlet device to apply a specific flow rate to a furrow and a collection sump with a pump to return tail water to the inlet device. Water infiltrated by the soil in the test section (typically 10 meters) is replaced with water from a reservoir

to keep the flow rate constant. The rate of water infiltrated versus time is observed and plotted. Accumulated infiltration versus time is also plotted. An equation (typically for a curvilinear line) then represents the intake characteristics for that particular soil condition.

Initial intake Depth of water absorbed by a soil during the period of rapid or comparatively rapid intake following initial application. Expressed in inches per hour.

Instantaneous application rate The maximum rate, usually localized, that a sprinkler application device applies water to the soil, expressed in inches per hour. Instantaneous application rates of over 30 inches per hour have been measured near the ends of low pressure center pivot irrigation laterals.

Intake family curve, intake characteristic curve A set of accumulated intake versus time curves grouped into families having similar border or furrow intake characteristics. Intake family curves are unitless and do not represent the average infiltration rate. The infiltration process in borders differs from that in furrows, thus each irrigation system has a different set of intake family curves.

Intake family A grouping of intake characteristics into families based on field infiltrometer tests on many soils. Used to analyze and design border and furrow irrigation systems.

Intake rate The rate at which irrigation water enters the soil at the surface. Expressed as inches per hour. (See infiltration.)

Interception That part of precipitation or sprinkler irrigation system applied water caught on the vegetation and prevented from reaching the soil surface.

Inverted siphon A closed conduit with end sections above the middle section; used for crossing under a depression, under a highway or other obstruction. Sometimes called sag pipe.

Irrecoverable water loss Water loss that becomes unavailable for reuse through evaporation, phreatophyte transpiration, or ground-water recharge that is not economically recoverable.

Irrigable area Area capable of being irrigated, principally based on availability of water, suitable soils, and topography of land.

Irrigating stream (1) Flow for irrigation of a particular tract of land.
(2) Flow of water distributed at a single irrigation. Sometimes called irrigating head, normally expressed as a rate or volume.

Irrigation Applying water to the land for growing crops, reclaiming soils, temperature modification, improving crop quality, or other such uses.

Irrigation check (1) Small dike or dam used in the furrow or alongside an irrigation border to make the water spread evenly across the border.
(2) A plastic or canvas tarp dam placed in a field ditch to raise the

water level in the ditch for diversion onto a field.

Irrigation company A semi-public, private group, or commercial enterprise set up to deliver irrigation water.

Irrigation district, company A cooperative, self-governing semipublic organization set up as a subdivision of a state or local government to deliver irrigation water.

Irrigation efficiency (Ei) The ratio of the average depth of irrigation water beneficially used to the average depth applied, expressed as a percentage. Beneficial uses include satisfying the soil water deficit, leaching requirement for salinity control, and meeting other plant needs. Generally used to express overall field or farm efficiency, or seasonal irrigation efficiency.

Irrigation frequency, interval The time, generally in days, between irrigation events. Usually considered the maximum allowable time between irrigation's during the peak ET period.

Irrigation method One of four irrigation methods used to apply irrigation water: surface, sprinkle, micro, and subirrigation. One or more irrigation systems can be used to apply water by each irrigation method.

Irrigation scheduling Determining when to irrigate and how much water to apply, based upon measurements or estimates of soil moisture or crop water used by the plant.

Irrigation set The area irrigated at one time within a field.

Irrigation set time, irrigation period The amount of time required to apply a specific amount of water during one irrigation to a given area, typically refilling the plant root zone to field capacity minus expected rainfall.

Irrigation slope Elevation difference along the direction of irrigation expressed as, a percentage (feet per 100 feet) or foot per foot. Sometimes called irrigation grade.

Irrigation system Physical components (pumps, pipelines, valves, nozzles, ditches, gates, siphon tubes, turnout structures) and management used to apply irrigation water by an irrigation method. All properly designed and managed irrigation systems have the potential to uniformly apply water across a field.

Irrigation water management Managing water resources (precipitation, applied irrigation water, (IWM) humidity) to optimize water use by the plant. Soil and plant resources must also be considered.

Irrigation water requirement The calculated amount of water needed to replace soil water used by the crop (soil water deficit), for leaching undesirable elements through and below the plant root zone, plus other needs; after considerations are made for effective precipitation.

Julian day, day of year Sequential numbering of days starting January 1 as day one and continuing until the end of the year, December 31, as day 365 (leap year day 366).

Kinematic wave A method of mathematical analysis of unsteady open channel flow in which the dynamic terms are omitted because they are small and assumed to be negligible.

Land leveling, land grading, precision land leveling Shaping the surface of the soil to planned elevations and grades.

Laser controlled leveling or grading Land leveling or grading in which a stationary laser transmitter and a laser receiving unit mounted on each earthmoving machine are used for automated grade control.

Leaching fraction The ratio of the depth of subsurface drainage water (deep percolation) to the depth of infiltrated irrigation water. (See Leaching requirement.)

Leaching requirement (1) The amount of irrigation water required to pass through the plant root zone to reduce the salt concentration in the soil for reclamation purposes.
(2) The fraction of water from irrigation or rainfall required to pass through the soil to prevent salt accumulation in the plant root zone and sustain production. (See Leaching fraction.)

Leaching Removal of soluble material from soil or other permeable material by the passage of water through it.

Length of run The distance down the furrow, corrugation, or border to the planned end of irrigation, typically the edge of the field.

Limited irrigation Management of irrigation applications to apply less water than needed to satisfy the soil water deficit in the entire root zone. Sometimes called deficit or stress irrigation.

Line-source emitter Water is discharged from closely spaced perforations, emitters, or a porous wail along a micro irrigation lateral.

Long-path emitter Employs a long capillary sized tube or channel to dissipate pressure and discharge water in discrete droplets or seeps.

Long throated flume Open-channel flow measuring devices of various cross-sections, having three to five main sections. Their operation is based on critical flow occurring in a contracted throat, with parallel walls and level floor, that is long enough to produce nearly parallel flow streamlines. This allows accurate calibration by computational methods. The name usually refers to devices with contractions from the channel sides or from both the sides and bottom. Flumes with bottom-only contractions are traditionally referred to as a type of broad-crested weir, but are hydraulically the same as longthroated flumes.

Low energy precision application (LEPA) A water, soil, and plant management regime where precision down-in-crop
applications of water are made on the soil surface at the point of use. Application devices are located in the crop canopy on drop tubes mounted on low pressure center pivot and linear move sprinkler irrigation systems. Generally limited to circular plantings on less than 1 percent slopes and no translocation of applied water. Furrow dikes, good soil condition, and crop residue are usually required to control water translocation.

Low pressure in canopy (LPIC) A low pressure in-canopy system that may or may not include a complete water, soil, and plant management regime as required in LEPA. Application devices are located in the crop canopy with drop tubes mounted on low pressure center pivot and linear move sprinkler irrigation systems. Limited water translocation within the field and some minor nonuniformity of water application usually exists.

Lysimeter An isolated block of soil, usually undisturbed and in situ, for measuring the quantity, quality, or rate of water movement through or from the soil.

Management allowed depletion (MAD) The planned soil moisture deficit at the time of irrigation. It can be expressed as the percentage of available soil water capacity or as the depth of water that has been depleted from the root zone. Sometimes called allowable soil depletion.

Manufacturer’s coefficient of variation A measure of the variability of discharge of a random sample (of a given make, model, and size) of micro irrigation emitters, pressure regulators and sprinkler nozzles, as produced by the manufacturer and before any field operation or aging has taken place. It is equal to the ratio of the standard deviation of the discharge to the mean discharge of the emitters.

Matric potential Matric potential is a dynamic soil property and will be near zero for a saturated soil. Matric potential results from capillary and adsorption forces. This potential was formerly called capillary potential or capillary water.

Maximum application rate The maximum discharge, in inches per hour, at which sprinklers can apply water without causing significant translocation.

Microclimat Atmospheric conditions within or near a crop canopy.

Micro irrigation The frequent application of small quantities of water as drops, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line. The micro irrigation method encompasses a number of systems or concepts, such as bubbler, drip, trickle, line source, mist, or spray.

Mixed-flow pump A centrifugal pump in which the pressure is developed partly by centrifugal force and partly by the lifting action of the impellers in the water.

Moisture deficit,
soil moisture depletion The difference between actual soil moisture and soil moisture held in the soil at the field capacity.

Moisture stake See Tensiometer

Multi-outlet emitter Supplies water to two or more points through small diameter auxiliary tubing.

Multi-stage pump A pump having more than one impeller mounted on a single shaft.

Nappe Sheet or curtain of unsubmerged water flowing from a structure, such as a weir or dam.

Net irrigation The actual amount of applied irrigation water stored in the soil for plant use or moved through the soil for leaching salts. Also includes water applied for crop quality and temperature modification; i.e., frost control, cooling plant foliage and fruit. Application losses, such as evaporation, runoff, and deep percolation, are not included. Generally measured in inches of water depth applied.

Net irrigation water requirement The depth of water, exclusive of effective precipitation, stored soil moisture, or ground water, that is required for meeting crop evapotranspiration for crop production and other related uses. Such uses may include water required for leaching, frost protection, cooling, and chemigation.

Net positive suction head The head that causes liquid to flow through the suction piping and enter (NPSH) the eye of the pump impeller. Required NPSH is a function of the pump design and varies with the capacity and speed of the pump. It must be supplied by the manufacturer. Available NPSH is a function of the system in which the pump operates and represents the energy level in the water over vapor pressure at the pump inlet. The available NPSH must equal or exceed the required NPSH or cavitation occurs.

Nonpoint source pollution (NPS) Pollution originating from diffuse areas (land surface or atmosphere) having no well-defined source.

Non-saline sodic soil A soil containing soluble salts that provide an electrical conductivity of the saturation extract (ECe) less than 4.0 mmhos/cm and an exchangeable sodium percentage (ESP) greater than 15. Commonly called black alkali or slick spots.

Nutrient management Managing the application rate and Li~-’ing of fertilizers to optimize crop use and reduce potential pollution of ground and surface water.

Neutron gauge, neutron probe, neutron scattering device A nondestructive method, used primarily by researchers, to measure in situ soil moisture. High speed neutrons are emitted from the radioactive source. Electronic count of the returning slow speed neutrons (or reflected), primarily affected by hydrogen atoms in the soil, is calibrated to represent total soil-water content. When properly calibrated and used, the neutron moisture gauge is probably the most accurate and repeatable method to measure soil moisture. The equipment is expensive, data collection is time consuming, training and licensing for personnel using the gauge and for storage are required.

Operational spills Planned or emergency spills made along or at the end of an open ditch (lateral) in a community irrigation water delivery system. Planned spills include the discharge of administrative or carry through water carried in laterals, to allow turnouts to be opened and closed without precision management of lateral flow rates. Emergency spill structures include overflow structures to discharge precipitation runoff water that has entered an irrigation water delivery system, and relief gates to discharge irrigation water in case of ditch or structure failure. Typically planned and emergency spill structures discharge water into a natural watercourse or protected channel.

Opportunity time The time that water inundates the soil surface with opportunity to infiltrate.

Orifice emitter A micro irrigation system application device employing a series of orifices to dissipate pressure.

Orifice An opening with a closed perimeter through which water flows. Certain shapes of orifices are calibrated for use in measuring flow rates.

Overhead irrigation See Sprinkler irrigation.

Pan coefficient A factor to relate actual evapotranspiration of a crop to the rate water evaporates from a free water surface in a shallow pan. The coefficient usually changes by crop growth stage.

Parshall flume Open-channel water flow measuring devices which are a part of a group of short-throated flumes that control discharge by achieving critical flow with curving streamlines in a contracted throat section. The sidewallls of the throat section are parallel, but the floor slopes downward in the direction of flow then rises again in a diverging side wall section. Calibrations are based on laboratory ratings. The flume is used for measuring water flow rates with very small total head loss (also see venturi flume). Ten critical edges and surfaces must be met for construction of an accurate Parshall flume

Peak use rate The maximum rate at which a crop uses water, measured in inches (acre inches per acre) per unit time; i.e., inches per month, inches per week, inches per day.

Peak period ET The average daily evapotranspiration rate for a crop during the peak water use period. Sometimes commonly called peak period CU (consumptive use).

Penman-Monteith Method A (radiation and advection) method used to estimate reference crop evapotranspiration (ET0) using current climatic data including air temperature, relative humidity, wind speed, and solar radiation.

Percolation Movement of the water through the soil profile. The percolation rate is governed by the permeability or hydraulic conductivity of the soil. Both terms are used to describe the ease with which soil transmits water.

Permanent wilting point (PWP) The moisture percentage, on a dry weight basis, at which plants can no longer obtain sufficient moisture from the soil to satisfy water requirements. Plants will not fully recover when water is added to the crop root zone once permanent wilting point has been experienced. Classically, 15 atmosphere (15 bars) or 1.5 mPa, soil moisture tension is used to estimate PWP.

Permeability (1) Qualitatively, the ease with which gases, liquids, or plant roots penetrate or pass through a layer of soil
(2) Quantitatively, the specific soil property designating the rate at which gases and liquids can flow through the soil or porous media.

Pest management Management to control undesirable plants, animals, fungi, or bacteria that are troublesome, annoying, or degrading to crop quantity and quality.

Pesticide Any chemical agent used to control specific organisms. Includes insecticides, herbicides, and fungicides.

Phreatophyte transpiration Transpiration from water loving vegetation along streams and water bodies, generally considered a loss for irrigation purposes. Phreatophyte vegetation may be a highly valuable food source and habitat for fish and wildlife.

Potential evapotranspiration (ET_o) The maximum evapotranspiration that will occur when water is not limiting. In some methods of computing evapotranspiration, it is measured as evaporation of water from a free surface. When used as reference crop evapotranspiration, it is for either well watered short grass or alfalfa. Care should be used in determining which factors are used. Preferred term is reference evapotranspiration.

Project efficiency (Ep) The overall efficiency of irrigation water use in a project setting that accounts for all water uses and losses, such as crop ET, environmental control, salinity control, deep percolation, runoff, ditch and canal leakage, phreatophyte use, wetlands use, operational spills, and open water evaporation.

Rainfall management Managing soil, water, and plant resources to optimize use of rainfall

Rectangular weir Typically a sharp crested weir that is rectangular.

Reference crop evapotranspiration The evapotranspiration from thick, healthy, well maintained grass (or alfalfa) that does not suffer any water stress. The reference crop is used to represent the water use of a standard crop in that environment even though that crop may not be physically grown in the area. ETo is generally used when referring to clipped (2 to 5 inches high) grass as the reference crop. ETr is used for 8- to 12-inch-high, 2-year-old alfalfa.

Relative humidity The ratio of the amount of water vapor present in the atmosphere to the amount required for saturation at the same dry bulb temperature.

Replogle flume, ramp flume A modified broad crested weir located in a short flume, lined ditch or pipeline that causes a drop in the hydraulic grade line, for measuring water flow rates. With open channel flow, there is one critical surface, which is level. With closed pipeline flowing full, the same surface can be oriented in any position parallel to the direction of flow. Very little head loss is required to accurately measure water flow rate.

Return-flow facilities, reuse facilities A system of ditches, pipelines, pump(s), and reservoirs to collect and convey surface or subsurface runoff from an irrigated field for reuse. Sometimes called tailwater reuse facilities or pumpback facilities.

Reverse grade A slope or grade on a field surface, crop row, or channel that slopes in the direction opposite to the prevalent or desired grade.

Riparian (1) Typically that area of flowing streams that lies between the normal water line and some defined high water line.
(2) Pertaining to the banks of a body of water; a riparian owner is one who owns the banks.
(3) A riparian water right is the right to use and control water by virtue of ownership of the banks.

Root zone Depth of soil that plant roots readily penetrate and in which the predominant root activity occurs. Preferred term is plant root zone.

Rotational delivery system A management technique used for community irrigation water delivery systems in which water deliveries are rotated among water users often at a frequency determined by water supply availability rather than crop water need. This method of managing water deliveries results in some of the lowest on-farm irrigation water application efficiencies.

Row grade The slope in the direction of crop rows.

Runoff, runoff loss Surface water leaving a field or farm, resulting from surface irrigation tailwater, applying water with sprinklers at a rate greater than soil infiltration and surface storage, overirrigation, and precipitation.

Saline soil A non-sodic soil containing sufficient soluble salts to impair its productivity for growing most crops. The electrical conductivity (ECe) of the saturation extract is greater than 4 mmhos/cm, and exchangeable sodium percentage (ESP) is less than 15; i.e., non-sodic. The principal ions are chloride, sulfate, small amounts of bicarbonate, and occasionally some nitrate. Actually, sensitive plants are affected at half this salinity, and highly tolerant ones at about twice this salinity.

Saline-sodic soil Soil containing both sufficient soluble salts and exchangeable sodium to interfere with the growth of most crops. The exchangeable sodium percentage (ESP) is greater than or equal to 15, and electrical conductivity of the saturation extract (ECe) is greater than 4 mmhos/cm. It is difficult to leach because the clay colloids are dispersed.

Salinity The concentration of dissolved mineral salt in water and soil on a unit volume or weight basis. May be harmful or nonharmful for the intended use of the water.

Satiation To fill most voids between soil particles with water.

Saturation To fill all (100%) voids between soil particles with water.

Seepage, seepage loss, leakage 1. Water escaping below or out from water conveyance facilities, such as open ditches, canals, natural channels, and waterways.
2. Water emerging from the ground along an extensive line or surface as contrasted with a spring where the water emerges from a localized spot.

Semiarid climate Climate characterized as neither entirely arid nor humid, but intermediate between the two conditions. A region is usually considered as semiarid when precipitation averages between 10 inches (250 mm) and 20 inches (500 mm) per year.

SI units, International System of Units An international metric system developed by General Conference on Weights and Measures, CGPM. This system provides for an established single unit that applies for each physical quantity. Units for all other mechanical quantities are derived from these basic units. See chapter 16 for complete definitions and conversions for English to metric and metric to English units.

Siphon A closed conduit used to convey water across localized minor elevation raises in grade. It generally has end sections below the middle section. A vacuum pump is commonly used to remove air and keep the siphon primed. The upstream end must be under the water surface. Both ends must be under water, or the lower end must be closed to prime the siphon.

Siphon tube Relatively short, light-weight, curved tube used to convey water over ditchbanks to irrigate furrows or borders. The tube is typically between 1 and 4 inches in diameter 4 to 6 feet long.

Slide gate See Gate.

Sodic soil A non-saline soil containing sufficient exchangeable sodium to affect crop production and soil structure (including soil intake) under most conditions of soil and plant growth. The lower limit of the saturation extract exchangeable sodium percentage (ESP) of such soils is conventionally set at 15.

Sodium adsorption ratio (SAR) A relation between soluble sodium and soluble divalent cations that can be used to predict the exchangeable sodium percentage of soil equilibrated with a given solution. It is defined as follows:

$$\left(\frac{Na}{\frac{Ca+Mg}{2}} \right)^{1/2}$$

where: Na is sodium, Ca is calcium, and Mg is magnesium. Concentrations, denoted by parentheses, are expressed in moles per liter.

Sodium adsorption ratio, adjusted The sodium adsorption ratio of a water adjusted for the precipitation or dissolution of $Ca^{2\sim}$ and $Mg^{2\sim}$ that is expected to occur where a water reacts with alkaline earth carbonates within a soil. Numerically, it is obtained by multiplying the sodium adsorption ratio by the value (1 + 8.4 - pH~*), where pH~ is the theoretical calculation of the pH of water in contact with lime and in equilibrium with soil CO_2.

Soil aeration Process by which air and other gases enter the soil or are exchanged.

Soil crusting Compaction of the soil surface by droplet impact from sprinkle irrigation and precipitation. Well graded, medium textured, low organic matter soils tend to crust more readily than other soils.

Soil compaction Consolidation, increase in bulk density, reduction in porosity, and collapse of the soil structure when subjected to surface loads or the downward and shearing action of tillage implement surfaces.

Soil condition The physical condition of the soil related to farmability, tillage, crop growth, root development, water movement, water intake, structure, organic matter content, fertility, and biological activity.

Soil density Same as Bulk density.

Soil horizon A layer of soil differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics.

Soil moisture tension See Soil water tension.

Soil organic matter Organic fraction of the soil, including plant and animal residue in various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population.

Soil profile Vertical section of the soil from the surface through all its horizons.

Soil sealing The orientation and consolidation of soil particles in the intermediate surface layer of soil so that it becomes almost impermeable to water.

Soil series The lowest category of U.S. System of soil taxonomy. A conceptualized class of soil bodies having similar characteristics and arrangement in the soil profile.

Soil structure The combination or arrangement of primary soil particles into secondary particles, units, or peds that make up the soil mass. These secondary units may be arranged in the soil profile in such a manner as to give a distinctive characteristic pattern. Principal types of soil structure are platy, prismatic, columnar, blocky, granular, and massive.

Soil texture Classification of soil by the relative proportions of sand, silt, and clay present in the soil. USDA uses 12 textural classes.

Soil water, soil moisture All water stored in the soil. See Water holding capacity.

Soil-water content The water content of a given volume of soil. It is determined by: gravimetnc sampling and oven drying field samples (to a standard 105 °C), neutron moisture probes, time domain (TDR) and frequency domain reflectrometry (FDR) devices commonly called RF capacitance probes, tensiometers, electrical resistance blocks, thermal dissipation blocks, and feel and appearance methods.

Soil-water deficit or depletion Amount of water required to raise the soil-water content of the crop root zone to field capacity. It is measured in inches of water.

Soil-water potential Expresses the potential energy status of soil water relative to conditions associated with pure, free water. Total soil-water potential consists of osmotic potential, gravitational potential, and matric potential. See Soilwater tension and Matric potential.

Soil-water tension A measure of the tenacity with which water is retained in the soil. It is the force per unit area that must be exerted to remove water from the soil and is usually measured in bars, or atmospheres. It is a measure of the effort required by plant roots to extract water from the soil. Measurements are made using a tensiometer in the field (limited to 1 atmos) and a pressure plate apparatus in the laboratory.

Solar radiation (Rs) Radiation from the sun that passes through the atmosphere and reaches the combined crop and soil surface. The energy is generally in a waveband width of 0.1 to 5 microns. Net R~ is incoming minus reflected radiation from a surface.

Spile A conduit made of lath, pipe, or hose placed through ditchbanks to transfer water from an irrigation ditch to a field.

Spray irrigation The application of water by a small spray or mist to the soil surface where travel through the air becomes instrumental in the distribution of water. (used with sprinkler and micro irrigation methods).

Sprinkler distribution pattern Water depth-distance relationship measured from a single sprinkler head.

Sprinkler head A nozzle or device, which may or may not rotate, for distributing water under pressure through the air. Water is delivered to sprinkler heads by a system of pressurized pipelines.

Sprinkle irrigation Method of irrigation in which water is sprayed or sprinkled through the air to plant or ground surface. See Sprinkler irrigation system.

Sprinkler irrigation system Facility used to distribute water by the sprinkle irrigation method. Sprinkler systems are defined in the following general categories:
Periodic-move system—A system of laterals, sprinkler heads (gun types), or booms that are moved between irrigation settings. They remain stationary while applying water.
Fixed/solid-set system—A system of portable surface or permanently buried laterals totally covering the irrigated area or field. Typically several adjacent laterals or heads are operated at one time. Portable laterals are typically removed from the field at end of germination, plant establishment, or the irrigation season and are replaced the next irrigation season.
Continuous/self move system—A lateral, sprinkler (traveler), or boom that is continuous or self moving while water is being applied. Power for moving the facility is typically provided by electric or hydraulic (water) motors or small diesel engines.

Specific types of sprinkler systems under each general category include:
Boom—An elevated, cantilevered boom with sprinklers mounted on a central stand. The sprinkler-nozzle trajectory back pressure rotates the boom about a central pivot, which is towed across the field by a cable attached to a winch or tractor. Can be either periodic move or continuous move type system.
Center pivot—An automated irrigation system consisting of a sprinkler lateral rotating about a pivot point and supported by a number of selfpropelled towers. Water is supplied at the pivot point and flows outward through the pipeline supplying the individual sprinklers or spray heads. A continuous/self-move type system.
Corner pivot—An additional span or other equipment attached to the end of a center pivot irrigation system that allows the overall radius to

increase or decrease in relation to field boundaries.
Gun type—A single sprinkler head with large diameter nozzles, supported on skids or wheels. Periodically moved by hand or mechanically with a tractor, cable, or water supply hose. When the travel lane (or path) has been irrigated, the sprinkler head is relocated at the far end of the next travel lane and irrigation continues.
Lateral move, linear move—An automated irrigation machine consisting of a sprinkler line supported by a number of self-propelled towers. The entire unit moves in a generally straight path perpendicular to the lateral and irrigates a basically rectangular area. A continuous/self move type system.
Linear move—See Lateral move.
Portable handmove—Sprinkler system moved to the next irrigation set by uncoupling and picking up the pipes manually, requiring no special tools. A periodic move type system.
Side-move sprinkler—A sprinkler system with the supply pipe supported on carriages and towing small diameter trailing pipelines each fitted with several sprinkler heads. *A* periodic move type system.
Side-roll (wheel line) sprinkler—The supply pipe is usually mounted on wheels with the pipe as the axle and where the system is moved across the field by rotating the pipeline by engine power. *A* periodic move type system.
Solid-set, fixed-set—System that covers the complete field with pipes and sprinklers in such a manner that all of the field can be irrigated without moving any of the system. Laterals may be permanently buried or portable.
Towed sprinkler—System where lateral lines are mounted on wheels, sleds, or skids and are pulled or towed in a direction approximately parallel to the lateral. Rollers or wheels are secured in the ground near the main water supply line to force an offset in the tow path equal to half the distance the lateral would have been moved by hand. *A* periodic move type system.
Traveler—A single large, gun type sprinkler head with a large diameter nozzle mounted on a unit that is continuously moved across the field by supply hose or cable. The hose reel may be mounted with the sprinkler head on a trailer or on a separate trailer secured at the water supply main line, which is typically located at or near the center of the field. Sometimes called traveling gun or hosepull.

Static head The potential energy resulting from elevation differences. (See Head.)

Stilling well Pipe, chamber, or compartment having closed sides and bottom except for a comparatively small inlet connected to a main body of water. It buffers waves or surges while permitting the water level within the well to rise and fall with major fluctuations of the main water body. Used with water measuring devices to improve accuracy of measurement.

Stress irrigation Management of irrigation water to apply less than enough water to satisfy the soil-water deficiency in the entire root zone. Preferred term is limited irrigation or deficit irrigation.

Subhumid climate Climate characterized by moderate rainfall and moderate to high evaporation potential. *A* region is usually considered subhumid when precipitation averages more than 20 inches (500 mm) per year, but less than 40 inches (1,000 mm) per year.

Subirrigation Applying irrigation water below the ground surface either by raising the water table or by using a buried perforated or porous pipe system that discharges water directly into the plant root zone. Primary source of water for plant growth is provided by capillary rise of soil water above the water table (up flux) or capillary water movement away from the line source.

Surface irrigation Broad class of irrigation systems in which water is distributed over the soil surface by gravity flow (preferred term is surface irrigation method).

Surge irrigation *A* surface irrigation technique wherein flow is applied (typically to furrows or less commonly borders) intermittently during a single irrigation set.

Tailwater runoff Surface irrigation system water leaving a field or farm from the downstream end of a graded furrow, corrugation, border. Best surface irrigation distribution uniformity across the field is obtained with 30 to 50 percent tailwater runoff, unless tailwater reuse facilities are used.

Tensiometer Instrument, consisting of a porous cup filled with water and connected to a manometer or vacuum gauge, used for measuring the soil-water matric potential.

Total dissolved solids (TDS) The total dissolved mineral constituents of water.

Total dynamic head Head required to pump water from its source to the point of discharge. Equal to the static lift plus friction head losses in pipes and fittings plus velocity head.

Total suction head Head required to lift water from a water source to the centerline of the pump impeller plus velocity head, entrance losses, and friction losses in suction pipeline.

Translocation Movement of water to other area(s) than where it was applied.

Transpiration The process of plant water uptake and use, beginning with absorption through the roots and ending with transpiration at the leaf surfaces. See Evapotranspiration.

Trapezoidal flume *A* calibrated open-channel structure with sidewalls inclined to the horizontal, used to measure flow of water. Measurement is based on the principle of critical flow at a critical section.

Trapezoidal weir A sharp-crested weir of trapezoidal-shape.

Triangular weir *A* sharp-crested V-notch weir. Most common is 90 degree V-notch, but it can be any angle.

Trickle irrigation *A* micro irrigation system (low pressure and low volume) wherein water is applied to the soil surface as drops or small streams through emitters. Preferred term is Drip irrigation.

Turnout See Delivery box.

Unavailable soil water That portion of water in a soil held so tightly by adhesion and other soil forces that it cannot be absorbed by plants rapidly enough to sustain growth without permanent damage. The soil water remaining at the permanent wilting point of plants.

Valve A device to control flow that includes:
Pressurized system:
Air relief valve—Device that releases air from a pipeline automatically without permitting loss of water.
Air vacuum, air relief valve—Device that releases air from a pipeline automatically without permitting loss of water or admits air automatically if the internal pressure becomes less than atmospheric.
Backflow prevention valve—A check valve that allows flow in one direction. When closed, air is admitted to the low pressure (supply) side to prevent siphoning or backflow of water and chemicals to a water source.
Ball valve—A valve in a pipeline used to start or stop flow by rotating a sealed ball with a transverse hole approximately equal to the diameter of the pipeline. Ball rotation is typically 90 degrees for single-port control. With hole modifications, several outlets may be controlled. In this case, only partial rotation of the handle may be used. Ball valves should be opened and closed slowly to avoid high surge pressures. Headloss through a ball valve is very low.
Butterfly valve—A valve in a pipeline to start or stop flow by rotating a disk 90 degrees. The disk is about the same diameter as the pipeline. Butterfly valves should be opened and closed slowly to avoid high surge pressures (water hammer). Headloss through a butterfly valve is low.
Check valve—Valve used in a pipeline to allow flow in only one direction.
Drain valve—(a) Automatic has spring-loaded valve that automatically opens and drains the line when the pressure drops to near zero. (b) Flushing type has a valve on the end of a line to flush out dirt and debris. This may be incorporated into an end plug or end cap.
Float valve—A valve, actuated by a float, that automatically controls the flow of water.
Gate valve—A valve in a pipeline used to start or stop water flow. May be operated by hand with or with out mechanical assistance or

by high or low voltage (solenoid) electric controlled mechanical assistance. Gate valves consist of seated slide or gates operating perpendicular to the flow of water. Head loss through a gate valve is typically less than a globe valve, but more than a ball or butterfly valve.
Globe valve—A valve in a pipeline used to start or stop water flow. Globe valves stop flow by positioning a disk and gasket over a machined seat about the same diameter as the pipe. Globe valves are limited to smaller sizes because of the high velocities and very high head loss through the valve.
Pressure relief valve—A spring loaded valve set to open at a pressure slightly above the operating pressure, used to relieve excessive pressure and surges.
Solenoid valve—A misused term meaning a low voltage electrically controlled, mechanically actuated valve; typically a gate valve. Often a spring is used to hold the valve in a closed (or open) position when water pressure is low or electric energy is discontinued. (When ignition electric energy for an internal combustion engine or electric energy to a motor is discontinued, a spring closes the valve.)
Vacuum relief valve—Valve used to prevent a vacuum in pipelines and avoid collapsing of thin-wall pipe.

Non-pressure or very low pressure system:
Alfalfa valve—An outlet valve attached to the top of a short vertical pipe (riser) with an opening equal in diameter to the inside diameter of the riser pipe and a adjustable lid or cover to control water flow. *A* ring around the outside of the valve frame provides a seat and seal for a portable hydrant. Typically used in border or basin irrigation.
Orchard valve—An outlet valve installed inside a short vertical pipe (riser) with an adjustable cover or lid for flow control. Similar to an alfalfa valve, but with lower flow capacity. Typically used in basin irrigation.
Surge valve—A device in a pipe T fitting to provide flow in alternate directions at timed intervals. Used in surge irrigation.

Velocity head The energy head (H) created by water movement. The difference in elevation between the hydraulic grade line (HGL) and energy grade line (EGL). Described as H = V2/2g, where g = 32.2 ft’s/s (acceleration of gravity).

Venturi flume Flow measuring device with a contracted throat that causes a drop in the hydraulic grade line as well as an increase in velocity. Used for both open-channel and closed pipe flow measurement.

Vortex emitter *A* micro irrigation water application device that employs a vortex effect to dissipate pressure.

Water amendment (1) Fertilizer, herbicide, insecticide, or other material added to water for the enhancement of crop production.
(2) A chemical water treatment to reduce drip irrigation system emitter clogging.

Water conveyance efficiency Ratio of the volume of irrigation water delivered by a distribution system to the water introduced into the system.

Water holding capacity Total amount of water held in the soil per increment of depth. It is the amount of water held between field capacity (FC) and oven dry moisture level, expressed in inch per inch, inch per foot, or total inches for a specific soil depth. Soils that are not freely drained because they have impermeable layers can have temporary saturated conditions just above the impermeable layers. This can temproarily increase water holding capacity. Sometimes called Total water holding capacity. *See* Available water capacity.

Water leveling *A* method of landgrading wherein fields are divided into segments and flooded, and the highs are removed until all soil is beneath the water surface. Typically used with rice production.

Water rights State administered legal rights to use water supplies derived from common law, court decisions, or statutory enactments.

Water spreading Application of water to lands for the purpose of storing it as ground water for subsequent withdrawal, or *A* specialized form of surface irrigation accomplished by diverting water runoff from natural channels or water courses and spreading the flow over relatively level areas for soil storage or plant use. Typically does not supply full irrigation needs as they operate only when there is surface runoff from rainfall or snow melt events.

Water table control Controlling the water table elevation by pumping water into or discharging water from a planned subsurface irrigation or drainage system. The water table is maintained at a nearly constant elevation for each stage of plant growth and maturity.

Water table The upper surface of a saturated zone below the soil surface where the water is at atmospheric pressure.

Weirs Any of a group of flow measuring devices for open-channel flow. Weirs can be either sharp-crested or broad-crested. Flow opening may be rectangular, triangular, trapezoidal (cipolletti), or specially shaped to make the discharge linear with flow depth (sutro weir). Calibration is based on laboratory ratings.

Wilting point See Permanent wilting point.

Wind movement, daily wind run, wind speed Used to calculate reference crop evapotranspiration, usually expressed as wind run (average velocity, mph times time in hr/d).

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