Chapter 6 Irrigation System Design

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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

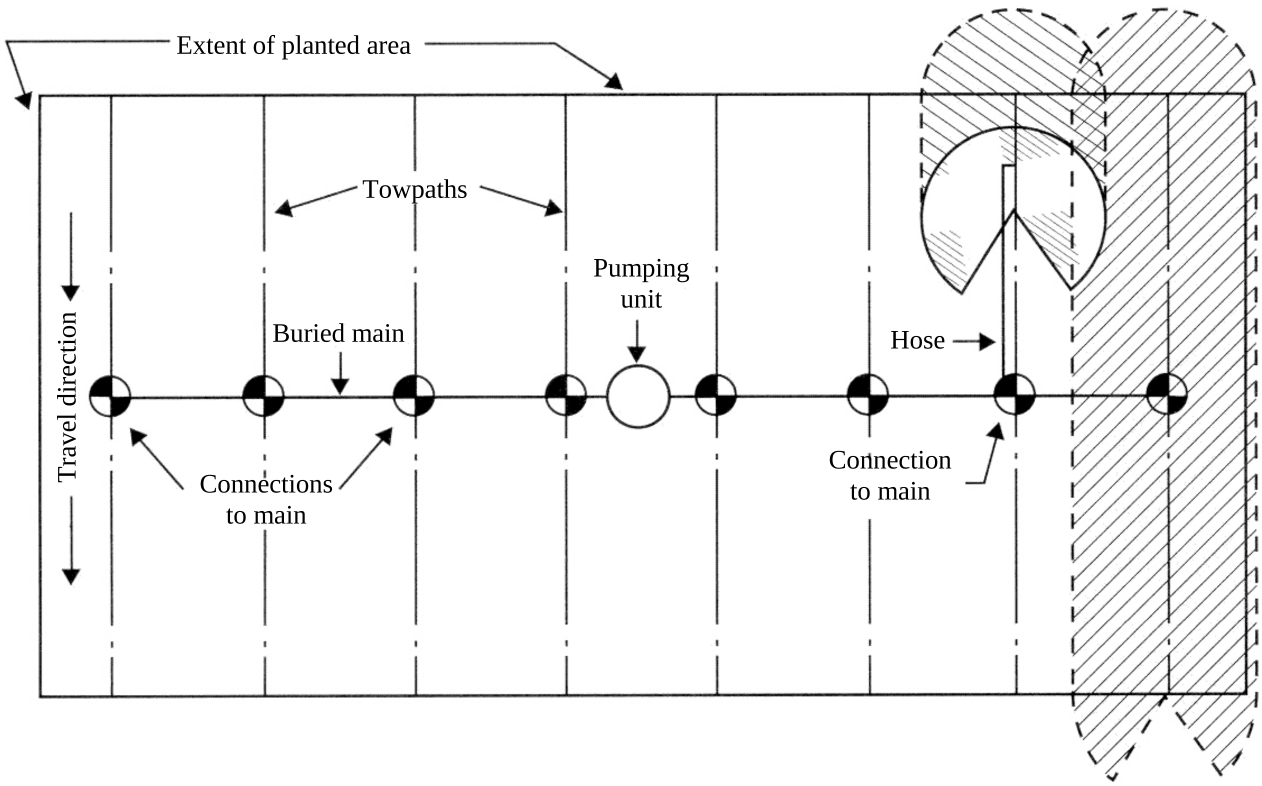

Table NJ 6.2 Typical discharge and wetted diameters for gun type sprinklers with 24° angles of trajectory and tapered nozzles operating when there is no wind

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:

$\frac{24}{12} \times 5.65 / 0.70 = 16$ 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.	ACRE INCHES DELIVERED IN		
per Acre	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

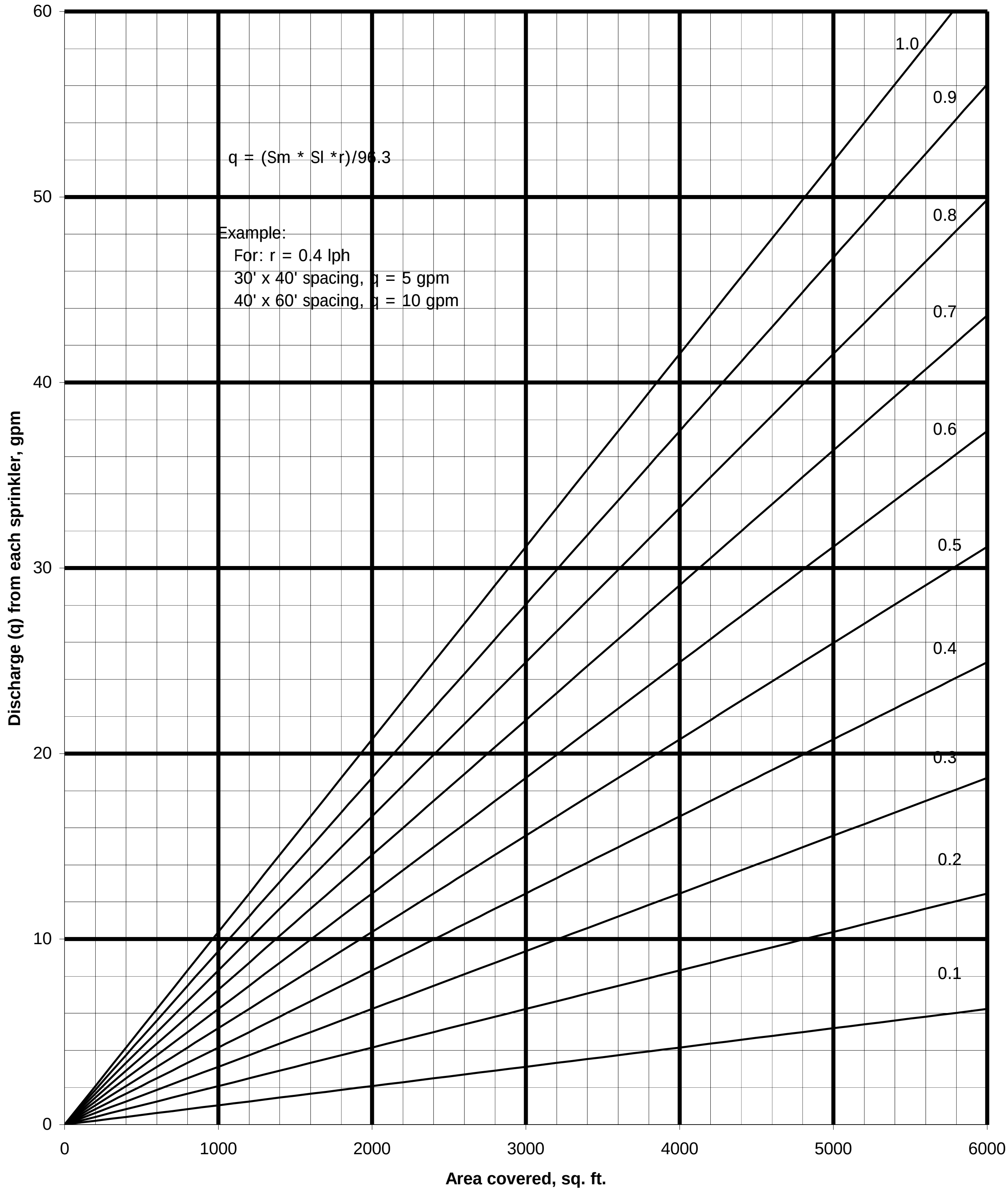


TABLE NJ 6.10 PERFORMANCE DATA OF TYPICAL SPRINKLERS

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, increase table values by 7 percent
For 40-foot lengths, decrease 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

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
	Friction Head Loss in Feet per Hundred Feet							
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

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

Table based on Hazen-Williams equation C = 150

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

SDR NO.	Conversion Factor
13.5	1.35
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 STANDAND DIMENSION RATIO - SDR = 21[1]

For IPS Pipe

Friction Read Loss in Feet per Hundred Feet

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.
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	l.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

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

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

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

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

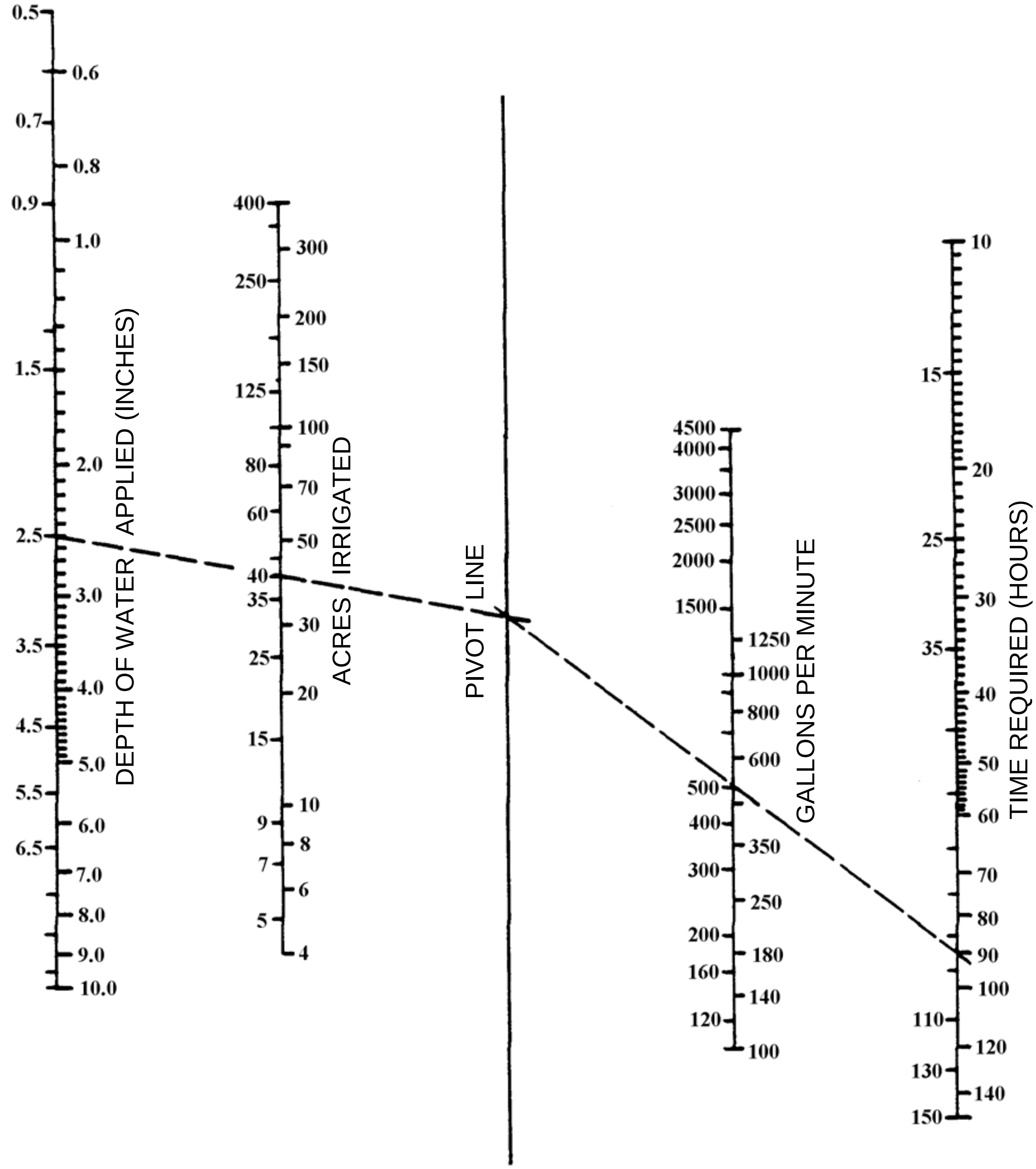
6. Compute pump capacity (NJIG Chapter 7).

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.

<u>Water Requirements</u>
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.

<u>Trees and Small Fruits</u>
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 stop watch.

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

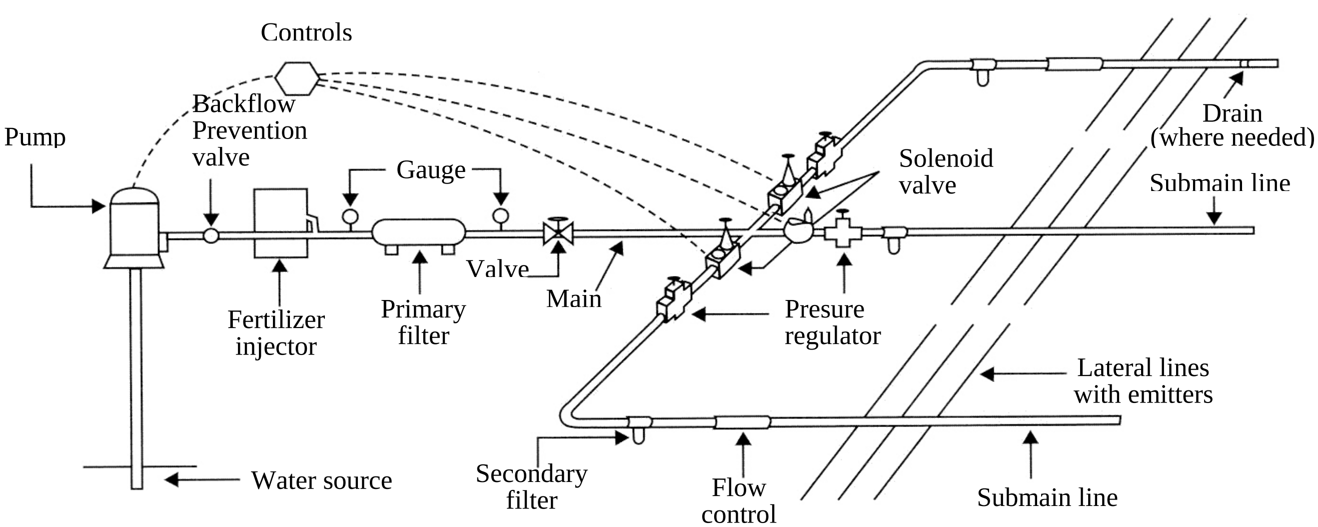


Table NJ 6-18 Plugging potential from irrigation water used in micro irrigation systems

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: atomospheric 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 is critical to ensure design standard emission uniformity and system efficiency. The following items are recommended:

Clean or backflush filter systems: This can be done manually or through automated 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/sq.ft 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. **Discharge rate should be within plus or minus 15 percent of the average system flow rate.**

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.

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

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.

often be modified by one of the following techniques to prevent the pressure variation in the subunit from being too great.

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.

<u>Designing Laterals And Submains</u>

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.

<u>1/</u> 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