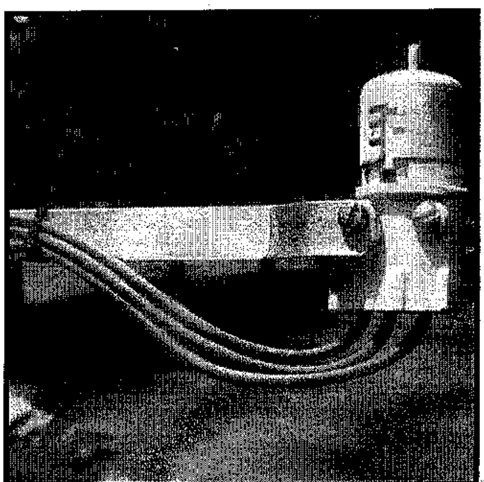

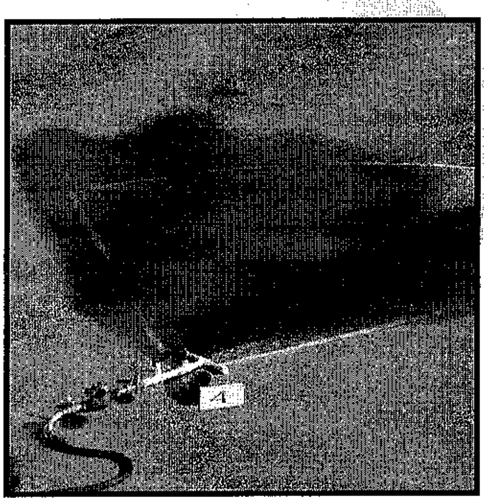

Advanced Landscape Irrigation Design & Management

2nd Edition

June 2015

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Irrigation ASSOCIATION®

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Foreword

When discussing advanced irrigation design for water conservation, we are referring to both the design and operation of a system that meets the goals for irrigation with the least amount of water. The goals of a landscape irrigation system are to help plants develop sound root systems, meet the functional aspects of the landscape, and maintain a pleasant appearance. Generally, either too much water or not enough water leads to diminished appearance and reduced longevity. So, for the system to meet the goals, it must be properly designed, installed, and operated. New irrigation technologies are developed every year, but without proper design and management a system cannot meet its goals. It is not reasonable to expect properly designed and managed systems to perform well indefinitely — they require maintenance. Consequently, advanced irrigation involves design, installation, management, and maintenance.

Good uniformity is essential for good system operation. The system must be designed properly in order to deliver good uniformity, but it must also be maintained. Uniformity alone is not sufficient for good system operation. Management is as important as design, and management along with uniformity will determine efficiency. This manual covers the design, management, and maintenance of landscape irrigation systems.

Acknowledgments

We would like to thank the Center for Irrigation Technology, Cal Poly Pomona, Joe Hung Udell Vis, Ramesh Kumar, Kurt Thompson, David Zoldoske, Joe Oliphant and Buckner Industries for their contributions to the original *Advanced Head Layout* manual.

This new manual and class would not have been possible without the efforts of a remarkable team of contributors that included Brent Mecham, Michael Prevost, Marvin Pascual, Scott Knowles, Art Elmers and Kurt Thompson. These regional authorized instructors already have full time jobs and still find time and effort to go above and beyond the call for support. The Irrigation Association is indebted to them.

Irrigation Uniformity and Efficiency

The ideal irrigation system will apply exactly the right amount of water the landscape needs at exactly the right time. Recognizing that no system is ideal, the designer works within the constraints of current technology. The first task is to divide the landscape into areas with the same or nearly the same microclimate conditions and plant material. This process is called zoning. Once the system has been zoned, the designer's goal is to have the system apply the same amount of water over the area of each zone. The problem is that irrigation systems do not apply exactly the same amount of water in every part of the zone.

Uniformity

Uniformity is a measure of the evenness of water application. Uniformity is measured based on where the water lands in the area — not where or how it might have infiltrated into the soil. One of the objectives of the designer and manager is to apply water so that it does not run off, so the assumption that the water in the soil is represented by the depth applied is reasonable but not exactly correct. Bear in mind that the plant uses the water from the soil, not from the surface where it was applied. Figure 1-1 shows examples of good uniformity and poor uniformity as represented by the water in the soil.

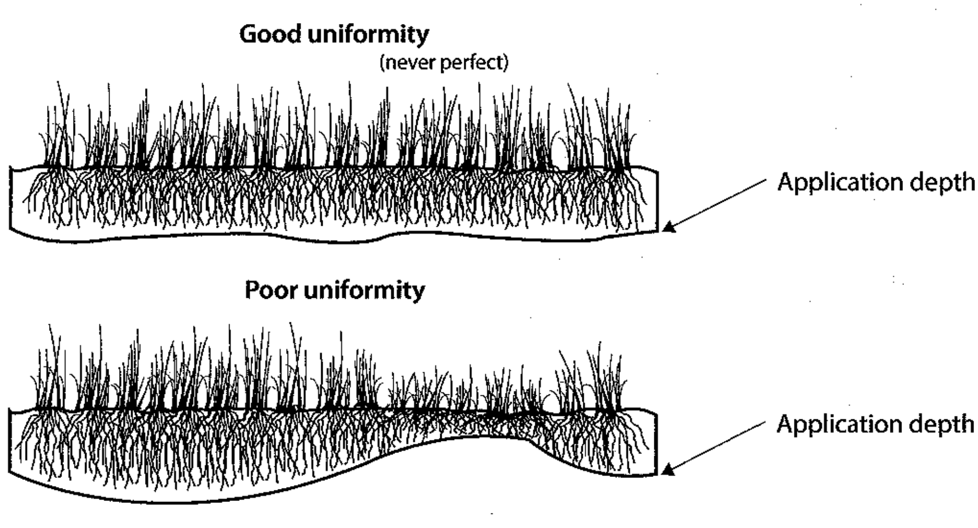
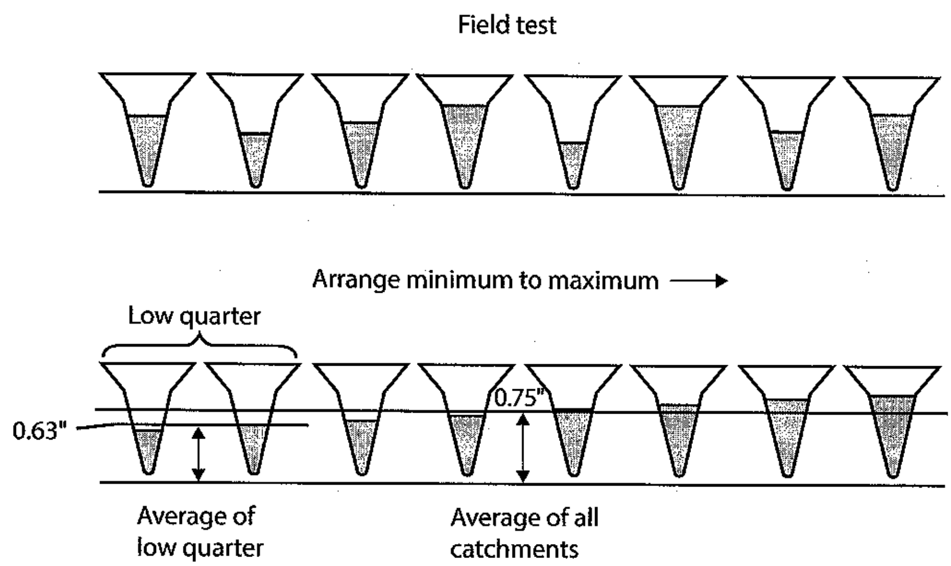


Figure 1-1
Distribution uniformity

It is much easier to measure the depth of water applied than it is to measure the depth of water in the soil. That is done by placing collectors or "cans" in the zone, running the system, and measuring the water in each collector. It is best to evenly space the collectors so that each represents approximately the same area. Then, the volume (or depth) collected in the cans is arranged from minimum to maximum. Figure 1-2 shows a typical set of collectors, first as they were in the field and then after they have been rearranged.

Figure 1-2
DU_{lq} catch devices



$$\text{Calculate} \quad DU_{lq} = \frac{63}{75} = 0.84$$

If a line is drawn through the top of the water in each collector, it results in a graph where area is on the horizontal axis and depth is on the vertical axis. This graph is known as a destination diagram. The most commonly used measure of uniformity is the distribution uniformity lower quarter [DU_{lq}]. In this process, the average of depths of the low quarter is divided by the average of depths from all collectors. In the example, the respective depths are 0.63 and 0.75 resulting in a DU_{lq} of 0.84, which is very good uniformity.

Uniformity is affected by sprinkler spacing, pressure, the characteristics of the individual sprinklers, and wind. Most manufacturers can give an estimate of expected uniformity for a specific spacing, pressure, and sprinkler/nozzle combination. Table 1-1 provides expected uniformities for rotary and spray sprinklers.

Table 1-1
Expected DU_{lq}

Sprinkler type	Achievable	Target	Historical*
Rotary sprinklers	0.75–0.85	0.65–0.75	0.55–0.65
Spray sprinklers	0.65–0.75	0.55–0.65	0.45–0.55

*If lower than this, consider system improvements.

An audit was recently conducted in a rotary sprinkler zone. The collector volumes were entered into an analysis program known as Audit/Sched/Mgr (available from IA). The input data is shown in figure 1-3.

Figure 1-3
Catch can test input data

Irrigation Association — **Catch Can Test**

Project Name	Example	Date	January 13, 2015
Address		Auditor	BvB
City, State	Anywhere, USA	Area/Zone/Station	sample 2

See instructions below on clearing input area

Test Area/Station	sample 2				
Catch Device Area (A_{CD})	16.5	in^2	Test Run Time (t_R)	15	min

Catch Device Volumes

1	58	17	95	33		49		65		81	
2	65	18	82	34		50		66		82	
3	112	19	53	35		51		67		83	
4	65	20	84	36		52		68		84	
5	110	21	73	37		53		69		85	
6	70	22	73	38		54		70		86	
7	55	23	87	39		55		71		87	
8	115	24	115	40		56		72		88	
9	65	25	82	41		57		73		89	
10	81	26	118	42		58		74		90	
11	57	27	75	43		59		75		91	
12	57	28	85	44		60		76		92	
13	72	29	98	45		61		77		93	
14	87	30	68	46		62		78		94	
15	93	31	86	47		63		79		95	
16	86	32	65	48		64		80		96	

Number Catch Devices	32	1/4 Number Catch Devices	8
Total Catch Volume	2587	Total Low Quarter	475
Average Volume (V_{avg})	80.84	Average Low Quarter (V_{lq})	59.38

Calculate Distribution Uniformity

$$DU_{lq} = \frac{\text{Average Low Quarter } (V_{lq})}{\text{Average Volume } (V_{avg})} = 0.73$$

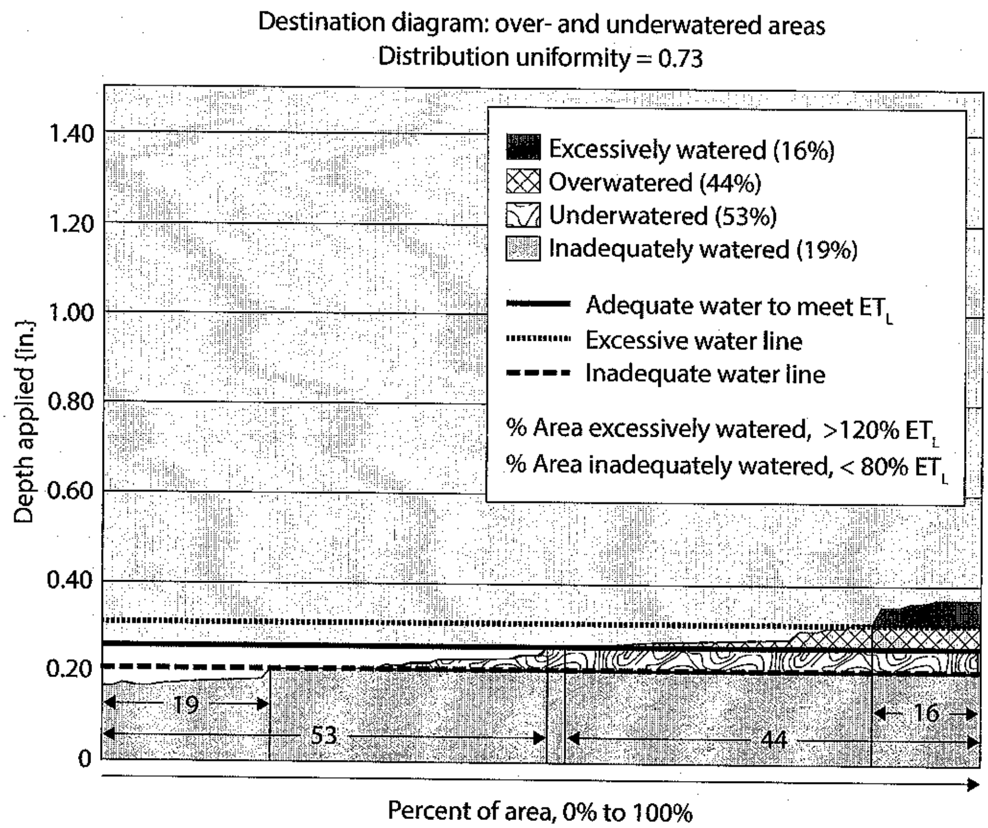
Calculate Net Precipitation Rate

$$PR_{net} = \frac{3.66 \times V_{avg}}{t_R \times A_{CD}} = 1.20 \text{ in./h}$$

There were 32 catch devices used, and the volumes caught were recorded in the Catch Device Volume spaces. The test run time was 15 minutes, and the catch device top area was 16.5 square inches. The average volume in the low quarter was 59.38 and the overall average was 80.84, resulting in a DU_{lq} of 0.73 and a net precipitation rate of 1.2 inches per hour. The DU_{lq} falls in the target range as shown in table 1-1.

The volumes from the collectors were arranged in ascending order and plotted against the area. At first, the average amount of water applied as determined by the precipitation rate and the run time was set to exactly what was needed to meet plant water usage. This run time is known as the lower boundary. Areas receiving 20 percent more than needed are considered excessively watered, and areas receiving 20 percent less than needed are considered inadequately watered. Because of the nonuniformity, 16 percent of the area was excessively watered and 19 percent was inadequately watered. The only way to decrease the excessively watered and inadequately watered areas at the same time is to improve uniformity. Figure 1-4 shows the result with this system when the run time is set to have the average amount equal the needed landscape evapotranspiration [ET_L].

Figure 1-4
Run time set at lower limit



This system will likely not meet the goal of the irrigation system because 19 percent of the area is not receiving adequate water. The only solution (without redesigning the system) is to increase the run time. IA has developed a process for increasing the run time of a system within reasonable limits. It involves the use of a scheduling multiplier.

Scheduling Multiplier

Because sprinkler systems are not perfect at applying water evenly across the area, the scheduling multiplier [SM] is used to help estimate the additional amount of water required to achieve an acceptable appearance. This is usually focused on the turf areas in the landscape where the lack of uniformity can manifest itself as dry spots or stressed areas within the irrigation zone. The typical practice to apply more water is to increase the run time on the controller. The SM provides guidance on how much extra time could be needed. It helps determine the upper scheduling boundary by increasing the number of minutes that sprinklers would operate to deliver an adequate amount of water. There are many other factors that influence how much extra water should be applied, including the required appearance, use of the turfgrass area, and horticultural maintenance practices. The SM also partially recognizes that there is lateral movement of water in the soil. The scheduling multiplier is based upon the following equation:

Equation 1-1

$$SM = \frac{1}{0.4 + \left(0.6 \times DU_{lq}\right)}$$

where

SM	=	scheduling multiplier {decimal}
DU_{lq}	=	lower quarter distribution uniformity {decimal}
0.4 and 0.6	=	constants

If the DU_{lq} is below 0.40, then time and effort should be spent identifying what can be done to improve system performance. This may include recommendations for improving maintenance or to seek the services of a certified designer and/or contractor to identify the factors that are causing such poor performance. When the uniformity is low, it is hard to justify the amount of additional water needed to minimize stressed areas and achieve an acceptable appearance. When additional minutes of run time become excessive, runoff potential increases, and it becomes more difficult to do proper maintenance if the sprinkler system is operating beyond its desired or designated water window.

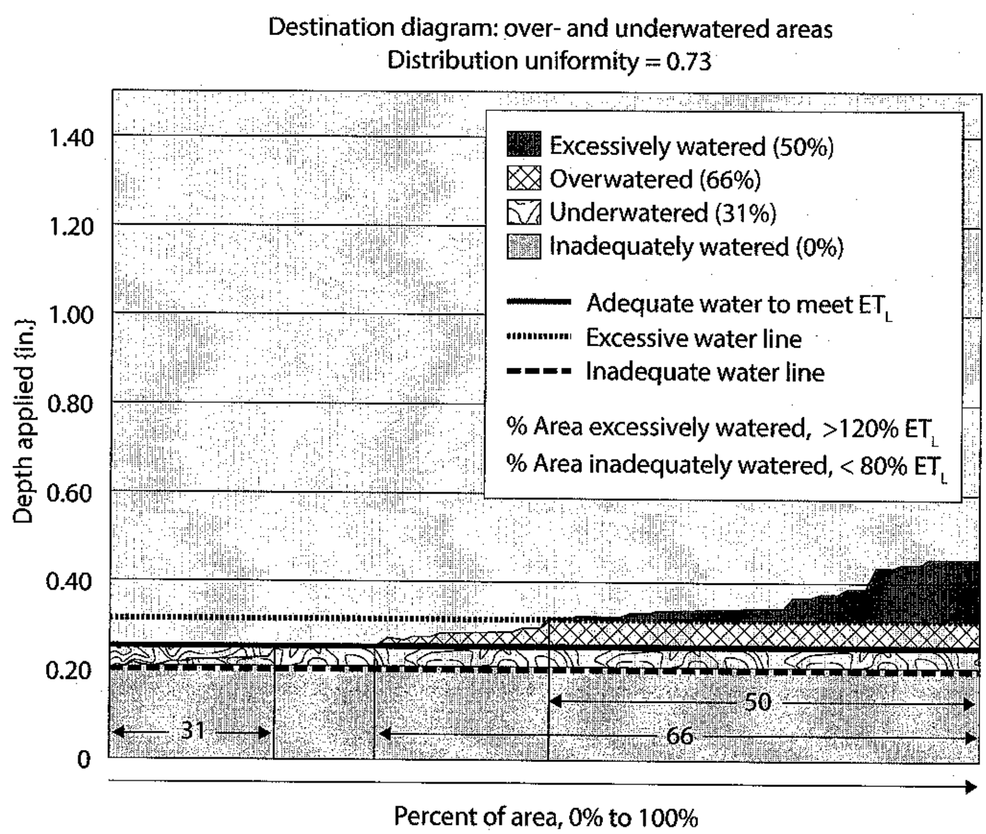
Table 1-2 is a reference for the SM that corresponds to the measured DU_{lq} for a particular sprinkler zone or area. The SM is a quick way to determine how much extra water could be applied. For example, a DU_{lq} of 0.60 has an SM of 1.32, which indicates that about one-third more water would be applied.

Table 1-2
Conversion table from DU_{lq} to scheduling multiplier

DU_{lq}	SM	DU_{lq}	SM	DU_{lq}	SM
1.00	1.00	0.78	1.15	0.58	1.34
0.98	1.01	0.76	1.17	0.56	1.36
0.96	1.02	0.74	1.18	0.54	1.38
0.94	1.04	0.72	1.20	0.52	1.40
0.92	1.05	0.70	1.22	0.50	1.43
0.90	1.06	0.68	1.24	0.48	1.45
0.88	1.08	0.66	1.26	0.46	1.48
0.86	1.09	0.64	1.28	0.44	1.51
0.84	1.11	0.62	1.30	0.42	1.53
0.82	1.12	0.60	1.32	0.40	1.56
0.80	1.14	Fix the sprinkler problems if below 0.40			

In the example from the catch test, the SM is 1.19. Multiplying the SM by the lower boundary and setting that as the run time (this is known as the upper boundary) results in the destination diagram shown in figure 1-5.

Figure 1-5
Run time set at upper limit



By increasing the run time to the upper boundary, the inadequately watered area has been eliminated. None of the area is inadequately watered. However, 66 percent, or two-thirds, of the area is now overwatered and 50 percent is excessively watered.

Efficiency

The next step in this examination of the system is to look at the efficiency. Application efficiency is generally defined as the water applied to the plant that is needed divided by the total water applied. It is beyond the scope of this discussion to show how that is done, but the efficiency of the system at the lower boundary is at best 91 percent, and the efficiency of the system at the upper boundary is 79 percent. By increasing the run time to avoid underwatering due to nonuniformity, the system efficiency went from a possible 91 percent to a possible 79 percent, or a 12 percent decrease.

The efficiencies are stated as "possible" because there are other factors that can cause the efficiency to be reduced. Reasons for efficiency reduction include runoff, improperly installed or improperly operating sprinklers, wind, water landing outside the target area, line drainage to low heads, and many others.

A significant factor in efficiency relates to the amount of water that lands on the area to be irrigated. This implies that some water does not land on the designated area, and that is often the case. Water that lands on hardscapes (e.g., driveways, sidewalks, and parking lots) is not usable and leads to inefficiency. Furthermore, even if the water lands where it is needed, if the precipitation rate exceeds the soil infiltration rate, it might run off and once again lead to inefficiency.

Chapter 2

Spacing and Pressure

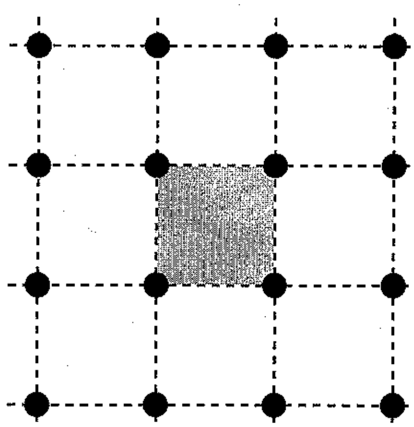
In chapter 1, the significance of uniformity on water use and efficiency was discussed. In this chapter, some of the key factors that influence uniformity will be covered. The two most significant factors affecting uniformity are spacing and pressure.

Spacing

Spacing refers to the distance between sprinklers. That involves both the arrangement of the sprinklers and the distance between them. While most discussions of spacing arrangements center on regular spacing (i.e., rectangular or triangular), many landscape installations involve irregular spacing. A key step in the design of any sprinkler system is deciding where to place the sprinklers. Making the right sprinkler placement decisions requires an understanding of the underlying objective behind all sprinkler spacing decisions: providing a uniform application of water. Uniformity of application relates to sprinkler spacing through the concept of overlap — the fact that any one location in the irrigated area is watered by more than one sprinkler. Choosing the best sprinkler spacing depends on sprinkler characteristics and the layout of the site to be irrigated. Additional factors may need to be considered, especially prevailing wind conditions anticipated during the times of irrigation.

Regular Arrangement of Sprinklers

While it is not always possible, sprinklers are often arranged following a regular geometric pattern. Examples are shown in figures 2-1 and 2-2 illustrating square spacing and equilateral triangular spacing arrangements, respectively.



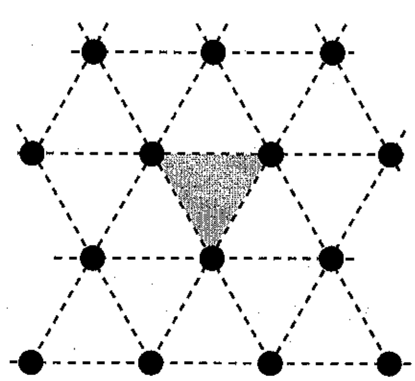


Figure 2-1 (left)
Arrangement of sprinklers in a square pattern

Figure 2-2 (right)
Arrangement of sprinklers in an equilateral triangular pattern

Sprinkler Spacing Distances

Sprinkler spacing distances specify the dimensions of the sprinkler pattern arrangement if there is a regular pattern to the arrangement. Normal practice is to space sprinklers so that the most distant water from one sprinkler just reaches the next. This is called head-to-head spacing. Most distribution patterns of sprinklers have been designed to give the best uniformity when they are spaced head-to-head. Looking at the line between two adjacent sprinklers (one located at 0 [left] and one located at 10 [right]) in figure 2-3, the two sprinklers exactly complement each other resulting in a perfectly uniform total application.

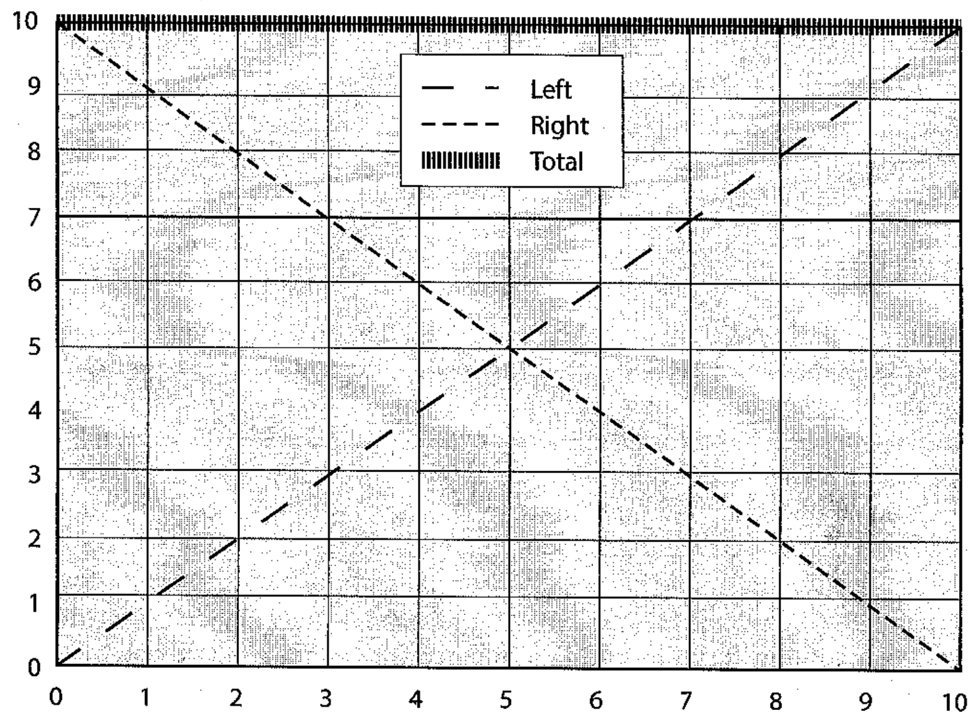


Figure 2-3
Ideal pattern from two overlapped sprinklers

Only the edges of the pattern as shown above have exactly uniform application, and there is a variation in depth in the rest of the area. There are several ways to show the depths; one is to show a three-dimensional representation of the depth of water. An example is shown below in figure 2-4. The scale has been distorted to show differences. However, the range of values is only from 10.2 to 12.4 with an average of 10.9. The high value is 14 percent more than the average, and the low is 6 percent less than the average. Rescaled as in figure 2-5, the uniformity is better shown, and it is excellent with a DU_{lq} of 94.3. The difference between figure 2-4 and figure 2-5 is the scale. From the big picture point of view, figure 2-5 shows that the water depth is quite uniform. However, when scaled as though looking through a microscope as in figure 2-4, there are noticeable differences in the depth. Irrigators generally take the big picture point of view.

Except for the small high point in the center of figure 2-4, the high values aren't clustered together, nor are the lows. This lessens the overall effect of nonuniformity.

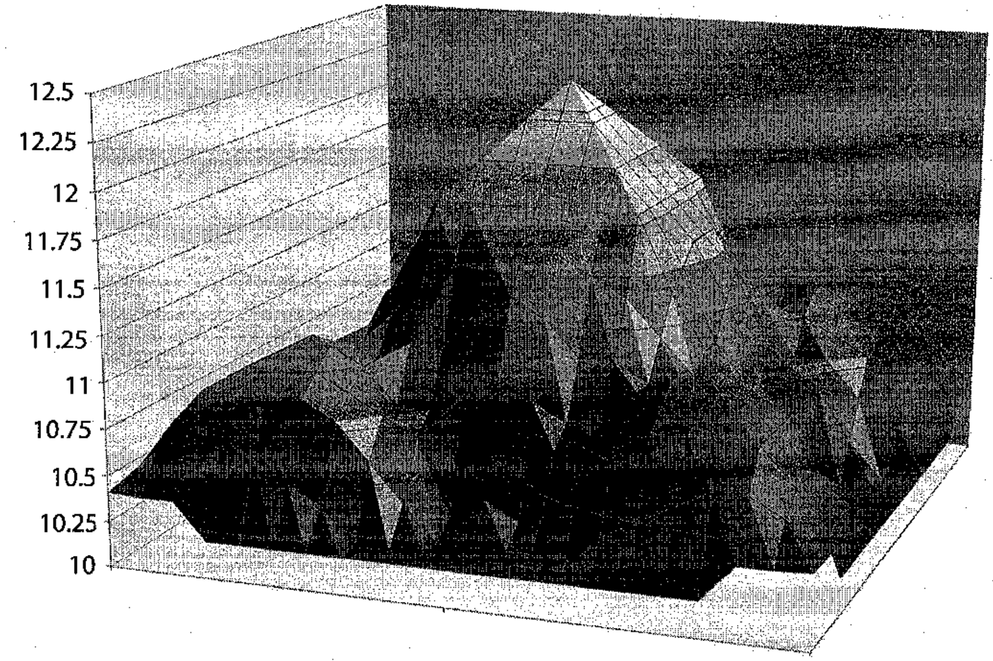


Figure 2-4
Three-dimensional representation of uniformity

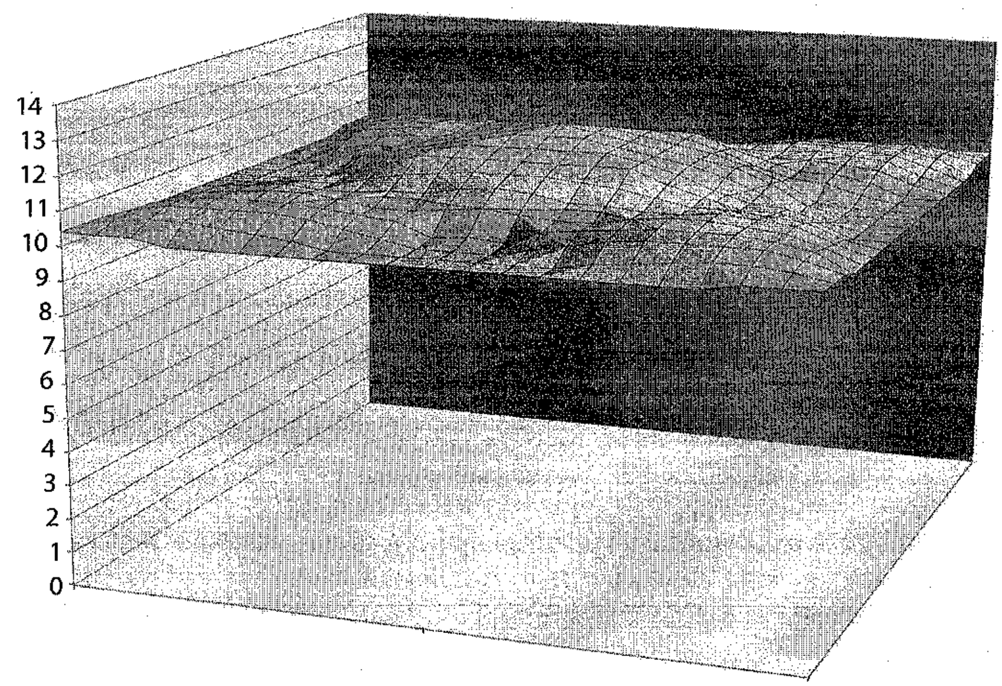


Figure 2-5
Rescaled three-dimensional representation of uniformity

The most common method to indicate the depth of water is with shading. The same chart is shown in figure 2-6 with shading. This type of representation is called a densogram.

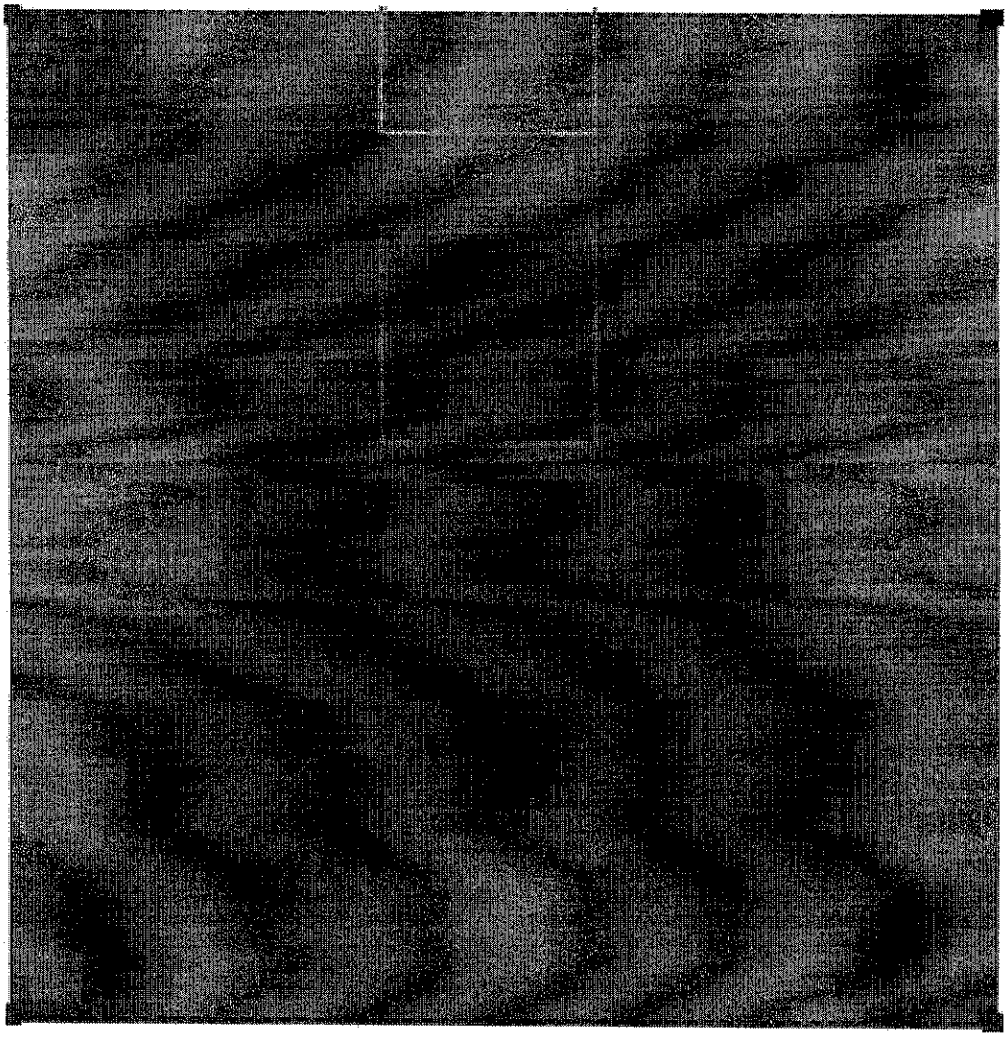


Figure 2-6
Densogram

It is impossible to achieve perfect uniformity with a rotary sprinkler, but very good uniformities can be achieved with proper design. A properly designed system can still be affected by wind, elevation change, and pressure change. Several sprinkler manufacturers offer computer programs to check the potential uniformity of a system design.

Increasing the distance between sprinklers or stretching the spacing will lead to reduced uniformity. The ideal sprinkler distribution pattern for a sprinkler is one where the depth linearly decreases with distance from the sprinkler. This pattern is a triangular distribution and was shown in figure 2-3. Stretching the spacing slightly beyond head-to-head (less than 10 percent) can slightly increase uniformity, but because many factors influence distribution such a pressure and wind, it is not recommended.

Pressure

There are two aspects of pressure that merit close attention. First, the pressure must be within the range recommended by the manufacturer for a given nozzle size. Usually that is midrange in the charts. Pressure affects the flow rate, drop size, distance of throw, and distribution pattern. Low pressures result in lower flow, larger drops, shortened distance of throw, and altered distribution patterns. A shortened distance of throw is equivalent to stretching the spacing. High pressure results in higher flow, smaller drops, slightly increased distance of throw, and altered distribution patterns.

The second factor in pressure is that all sprinklers should have the same pressure within ±10 percent. Pressure is affected by elevation and friction loss, so hydraulics play a major role in sprinkler system design. Hydraulics are covered in chapter 4 of this manual. Specifically, example 4-2 shows the effect pressure has on flow rate of a sprinkler. A 12 percent difference in pressure will result in a 6 percent difference in flow rate. These differences in flow rate will result in a difference in amount of water applied. Pressure differences usually result from hydraulics and/or elevation and because of that high pressures are clustered together and low pressures are clustered together. Hence, the wet spots are together and the dry spots are together. In figure 2-4, it is apparent that the low values aren't clustered together, but if a system had a 12 percent difference in pressure, the highs and lows would likely be together, and the effect of nonuniformity would be very obvious. The point of this discussion is to show that modest pressure differences can result in high or low spots in water applied and that the spots are clustered together.

Pressure Regulation and Variable Frequency Drive Pumps

Many irrigation systems involve multiple zones and a pump. It is difficult to design the flows in all the zones to be the same or nearly the same, and different zones will have differing pressure requirements. With a conventional pump, this means that each zone will require pressure-reducing valves to achieve the proper pressure. With systems involving individual head control, the process of achieving the proper pressure is very difficult as the pump will shift on the pump curve to match the system. The designer should consider the use of a variable frequency drive [VFD] pump in these cases. A VFD pump can be set to automatically adjust the speed of the pump (and hence the pressure) to the desired pressure across a wide range of flows. The main advantage is that considerably less energy is consumed in pumping because the system does not waste energy in pressure-reducing valves. Furthermore, changes in system demand as zones are changed can be made smoothly resulting in less stress on the piping system. VFDs cost more than conventional pumps and involve programming to achieve the desired results.

Spacing Adjustment for Wind

Wind can affect the water coming out of a sprinkler in two ways: it can disrupt the stream causing additional breakup of the stream and it can blow the disrupted stream around causing the water to fall in areas where it is not intended. Of course, the stronger the wind, the greater the affect.

When the sprinkler is pointing *into* the wind, the wind adds to the stream breakup and pushes the stream back towards the sprinkler. As a result, the upwind radius is shortened. When the sprinkler is pointing *with* the wind, the wind helps carry the water through the air and the downwind radius is extended. Usually the upwind radius is shortened more than the downwind radius is extended. So, there is a *net loss of diameter* in the direction of the wind.

The radius of throw is shortened in both crosswind directions. This is probably due to the wind's ability to add to the natural breakup of the sprinkler stream. The result is a *net loss of diameter* in the direction perpendicular to the wind.

The combined result of these two effects is a reduction in the area covered by each individual sprinkler affected by wind distortion.

Adjustment for Wind[1]

After establishing the effect wind has on sprinkler patterns, it is easier to determine what must be done to counteract those effects. If the designer is anticipating consistent windy conditions during the planned irrigation times, some adjustments to "no-wind" sprinkler spacings may be necessary. Since wind reduces the overall wetted area achieved by each sprinkler, the designer must reduce sprinkler spacing distances to maintain adequate overlap.

If a certain relative spacing would provide adequate uniformity under no-wind conditions, then as wind reduces the effective diameter of throw, the absolute spacings must also be reduced to maintain the same relative spacing proportions.

Wind-Distorted Sprinkler Patterns

Before determining how to adjust sprinkler spacing decisions to compensate for wind effects, it is necessary to understand how the wind distorts sprinkler patterns. Figure 2-7 shows densograms for individual sprinkler tests conducted under windy conditions. Overlaid on the densograms are contour plots showing lines of equal application amounts and circles showing the normal coverage of the sprinklers under no-wind conditions.

The distorted sprinkler patterns shown in figure 2-7 display characteristics similar to those of many other wind-distorted sprinkler patterns studied.

[1] This section discusses adjustments that can be made by the irrigation *system* designer. Sprinkler manufacturers can also make certain sprinkler models or options available to reduce adverse effects of wind on sprinkler coverage. These may include special nozzle designs, lower nozzle angles, flow straightening vanes, and other measures. Check with equipment suppliers and sprinkler manufacturers' catalogs for recommendations on the selection of these products and application recommendations, such as for riser height and operating pressure.

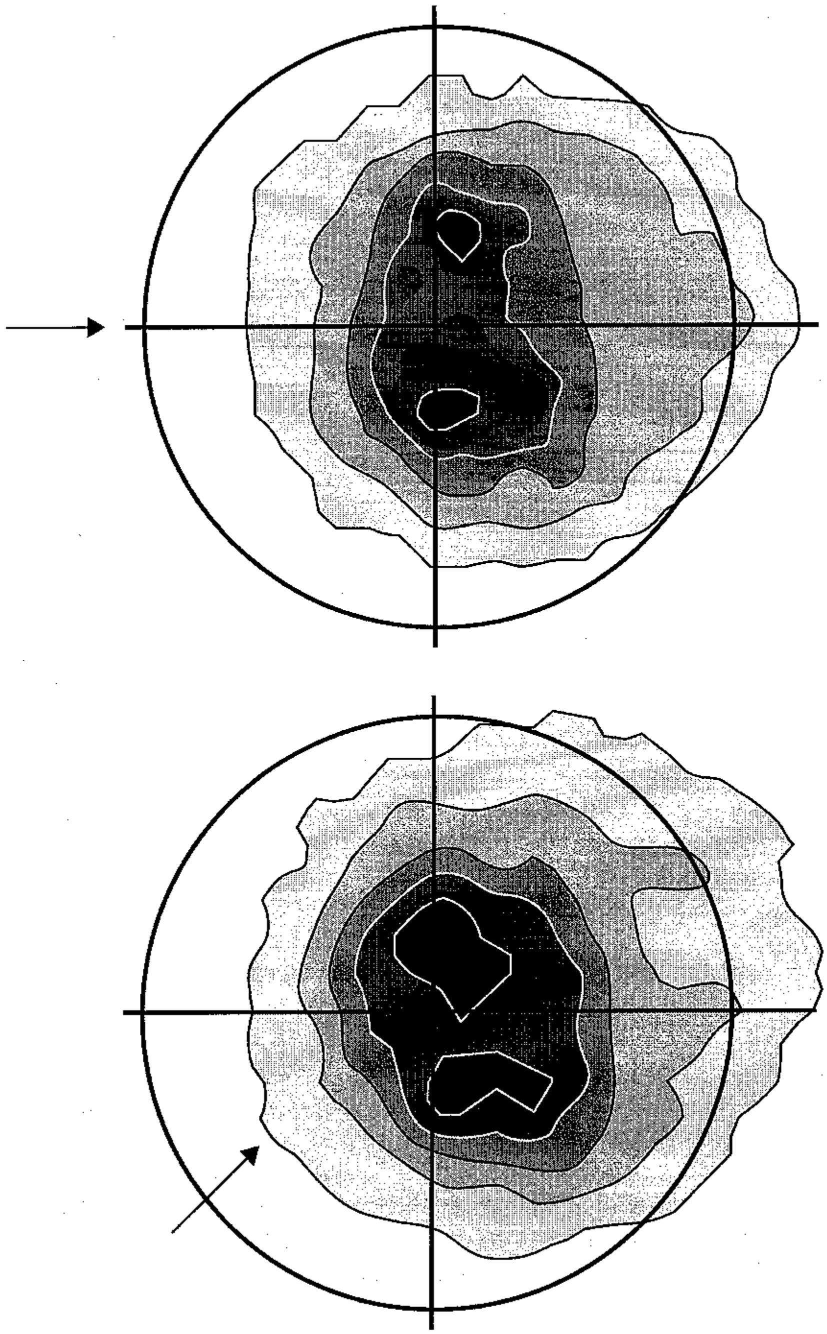


Figure 2-7
Impact sprinkler patterns distorted by a 7.3 mph wind (top) and a 7.7 mph wind (bottom). Sprinklers are located at the centers of the circles where the horizontal and vertical reference lines intersect. Arrows mark the wind directions.

Spacing Recommendations

The recommendations in table 2-1 have been compiled from a number of sources. While all sources don't completely agree, the recommendations shown here represent the general consensus.

Spacing recommendations are given in relative terms, as a percentage of the diameter of throw. The spacings given represent the *maximum* that should normally be considered for the conditions listed.

Table 2-1
Maximum recommended sprinkler spacings (percent of diameter)

Line #	Average wind speed (mph)	Spacing between sprinklers [S_s]	Spacing between rows of sprinklers [S_r]
For square spacings			
1	0–3	55%	[same as S_s]
2	4–7	50%	[same as S_s]
3	8–12	45%	[same as S_s]
For equilateral triangular spacings			
4	0–3	60%	[$0.866 \times S_s$]
5	4–7	55%	[$0.866 \times S_s$]
6	8–12	50%	[$0.866 \times S_s$]
For rectangular spacings			
7	0–3	50%	60%
8	4–7	45% (40%)*	60% (55%)
9	8–12	40% (30%)	60% (50%)
For staggered triangular spacings			
10	0–3	50%	60%
11	4–7	45% (40%)	60% (55%)
12	8–12	40% (30%)	60% (50%)

*Values in parentheses are recommendations from more conservative authorities and may be more appropriate in circumstances when higher uniformity must be maintained.

Wind Summary

Wind can disrupt a sprinkler's stream and distort its distribution pattern.

Wind-distorted sprinkler patterns typically exhibit both a net loss of diameter in the direction of the wind and a net loss of diameter in the crosswind direction. The combined result is a reduction in the area covered by each individual sprinkler affected by wind distortion.

Some adjustment in no-wind spacings may be necessary if windy conditions are anticipated during planned irrigation times. Since wind reduces the overall wetted area achieved by each sprinkler, the designer must reduce sprinkler spacing distances to maintain adequate overlap.

Staggered triangular spacings and comparable square or rectangular spacings have the same susceptibility to uniformity reduction due to high wind. Equilateral triangular spacings are better able than square spacings of the same distance between sprinklers to resist uniformity reduction due to wind. This is because the geometry of the equilateral arrangement results in a closer distance between rows of sprinklers than the square spacing arrangement.

Advanced Strategies

Chapter 3

There are several advanced strategies that can be employed in landscape sprinkler design and operation. Perhaps the most significant strategy in design is to put the water where it should be — specifically on the landscape needing irrigation and not on driveways, sidewalks, or buildings. While this may seem obvious, it isn't always achieved.

Outside-In Design

Design of landscape irrigation systems is generally an "outside-in" process, meaning that the system is designed first to the perimeter and then to the interior. The following explains this process:

1. Place sprinklers in corners.
2. Measure the distance along the shortest leg of the boundary between the corner sprinklers.
3. Select a sprinkler that has a distance of throw that will fit an integer number of times in the distance. The larger the distance chosen, the fewer sprinklers used, but the less likely it is that it will fit the entire perimeter.
4. Place sprinklers along the entire perimeter using the spacing equal to the distance of throw determined in step 3 above. This process may take more than one try. It is critical that sprinklers have head-to-head coverage for good uniformity.
5. Place sprinklers in the interior of the area using the same spacing. It may not be possible to have an equal area for each sprinkler. If not, the flow rate should be adjusted to match the area.
6. Select nozzles for each sprinkler. If they are matched precipitation rate sprinklers, the job is complete. If they are not, the flow rate of the nozzle should be proportional to the arc of operation. The arc of operation is determined by the shape of the perimeter.
7. It may not be possible to select nozzles with flow proportional to the arc of operation. If that is the case, zone sprinklers so that every sprinkler in the zone has the same flow proportional to the arc of operation.

Consider a turf area to be irrigated in the shape as shown in figure 3-1. The top straight leg is 96 feet; the right leg is 115 feet. Placing sprinklers in the corners is straightforward except for the lower left. At about halfway around the curve, it is 48 feet from the lower right sprinkler along the shortest leg. The curved perimeter on the left is about 140 feet. Based on the shortest leg, the distance of throw choices are 12, 16, 24, and 48. Table 3-1 shows the respective choices in spacing.

Figure 3-1
Sample design area

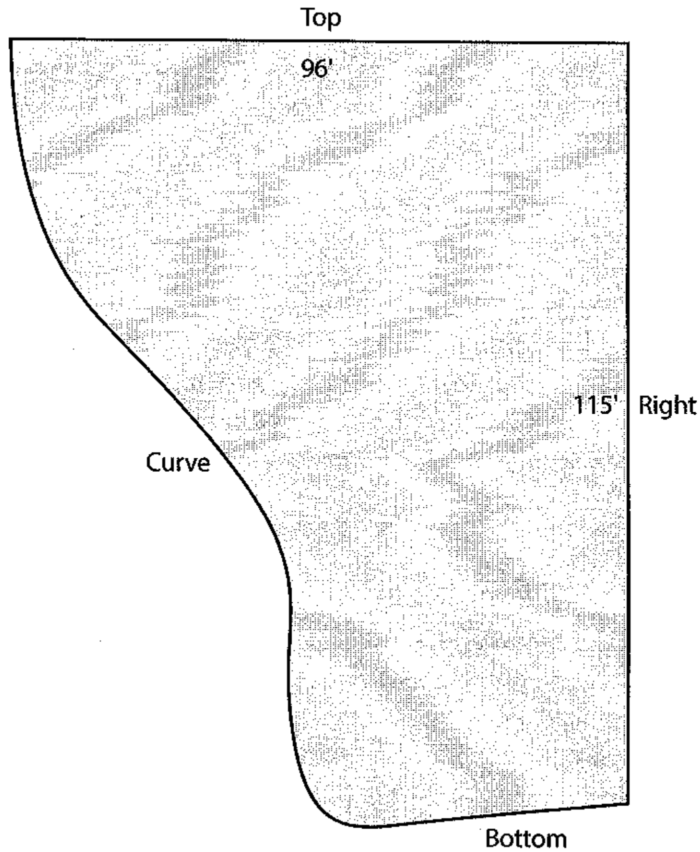


Table 3-1
Spacing choices for figure 3-1

Legs (distance in ft)			
Bottom (48)	Top (96)	Right (115)	Curve (140)
Spacing choices	Number of spaces		
12	8	9.58X	11.67X
16	6	7.19	8.75X
24	4	4.79	5.83
48	2	2.40X	2.92

Most of the choices can be eliminated (shown by an "X" next to the number of spaces in table 3-1) because they do not fit more than one leg. A distance of throw of 12 doesn't fit on the right and the curve, 16 doesn't fit well on the curve, and 48 doesn't fit well on the right. The distance of throw of 24 has a reasonable fit on the right and the curve if the spacing is adjusted slightly. By adjusting the right spacing to 23 feet and the curve spacing to 23.3 feet, fit is attained. The interior of the area can be fit with a square grid at about 24 feet. Figure 3-2 shows the final layout. A good fit would be one where the number of spaces is nearly a whole number and would round up. It is not a good fit if the number would round down because that would increase the spacing between sprinklers. For example, 7.19 would round down to 7 and that would increase the spacing. However, 4.79 is a good fit since it would round up to 5 and the spacing would be slightly decreased.

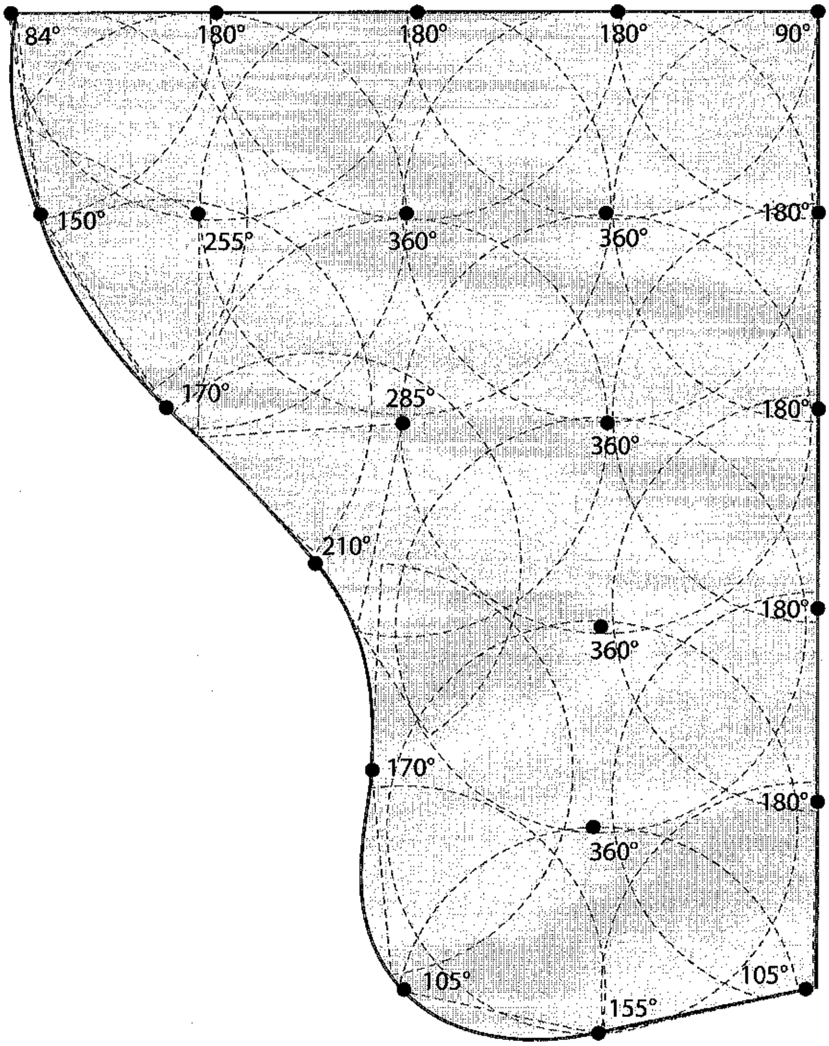


Figure 3-2
Sample design area with sprinklers and arcs noted

There are a total of 23 sprinklers with arcs of operation from 84 to 360 degrees. Table 3-2 shows the sprinklers and their required flow if the 180-degree sprinkler flow is 2 gpm. (Duplicate sprinklers are not shown.)

Table 3-2
Sprinkler arcs and relative flow requirements

Arc (degree)	Relative flow (gpm)
84	0.93
90	1.00
100	1.11
105	1.17
150	1.67
155	1.72
170	1.89
180	2.00
210	2.33
255	2.83
285	3.17
360	4.00

The first challenge is to find a sprinkler with the desired characteristics. The following guidelines can be used to determine what kind of sprinkler to use. Spray nozzles generally throw between 5 and 15 feet. Typically, they have application rates from 1 to 2 inches per hour. Multistream rotating nozzles throw from 12 to 30 feet and have application rates from 0.4 to 1.0 inches per hour. Small rotors throw from 15 to 30 feet, medium rotors from 25 to 50 feet, and impact rotors from 20 to 45 feet. Large gear-driven rotors can throw up to 150 feet.

The sprinkler needed in this scenario has a distance of throw of 25 feet, so likely it will be a multistream rotating nozzle or a small rotor. A Rain Bird 3500 series rotor with a 1.5 nozzle at 45 psi has a radius of 24 feet and flows 1.48 gpm giving a precipitation rate of 0.49 on square spacing. A Hunter PGJ rotor with a 1.5 nozzle at 40 psi throws 22 feet and flows 1.5 gpm giving a precipitation rate of 0.60 inches per hour on square spacing. Both of these choices would require nozzle selection and/or zoning. A matched precipitation rate sprinkler does not require nozzle selection. The Hunter MP3000 throws about 30 feet at 40 psi and gives a precipitation rate of 0.40 inches per hour. The MP 2000 throws about 20 feet and gives a precipitation rate of about 0.40 inches per hour. The Rain Bird 5000-MPR-25 (red) delivers a radius of 25 feet at 45 psi and a precipitation rate of 0.60 inches per hour on square spacing.

Cycle and Soak

The possible sprinkler selections above included the precipitation rate. It is important to design sprinkler systems so that the precipitation rate does not exceed the soil infiltration rate. If it does, then a strategy known as "cycle and soak" is used whereby the system is run for a short period of time, is shut off and time is allowed for the water to soak in, and then another cycle is begun. The soak time should be at least twice as long as the run time and as much as three times the run time. Some systems may require multiple cycles. While the time to runoff is dependent on many things including soil, thatch, slope, and compaction, figure 3-3 can be used as a general guideline for the amount of time a system can be run before runoff might occur.

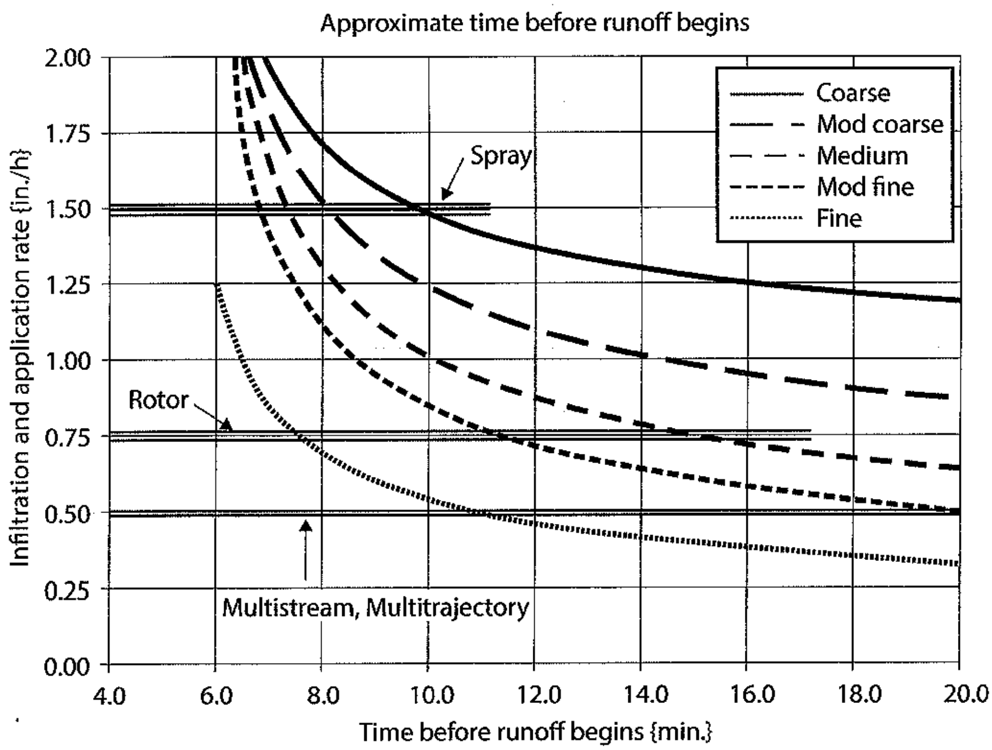


Figure 3-3
Soil infiltration rates for various soils

Allowing Room for Rainfall

The usual strategy for irrigating landscapes is to wait until the management allowed depletion has occurred and irrigate until the root zone is at field capacity. This strategy increases the risk that rainfall might either run off or deep percolate if it occurs too soon after irrigation. A strategy that can be employed is to allow soil moisture to fall to management allowed depletion but not completely fill the root zone. This leaves room for rainfall no matter when it occurs in the irrigation cycle. This requires precise irrigation and thorough knowledge of the soil. It also requires smaller and more frequent irrigation.

Inside-Out Design or Edge-In Design

There may be times when an inside-out design or edge-in design is better. If the area affected by sprinklers on the perimeter is small relative to the area affected by the interior, it might be better to design the system inside-out or edge-in and deal with the opposite perimeter. The area in figure 3-2 is almost all affected by the perimeter sprinklers. However, consider an area of a park or school ground where the perimeter is large (perhaps an acre or two) and rectangular. For example, consider an area 220 feet by 380 feet (1.92 acres) with trees along one 220-foot edge. It might be better to select a system with large rotors with a radius of throw of 50 feet. Starting on the unobstructed corner, place rotors at 50-foot spacing until the opposite edges are almost met. Then place 20-foot rotors along the obstructed edge and 30-foot rotors along the 380-foot perimeter. A system this large would probably involve multiple zones, so zoning similar rotors together should not be a problem.

Chapter 4

Design

Advanced design of landscape irrigation systems involves selecting sprinklers, properly placing them, designing the delivery system with controls and safeguards, and ensuring that proper pressure is maintained throughout the system. The system probably will require zoning and control valves, and good hydraulic design must be followed throughout the process.

Sprinkler Selection

Chapter 3 provided an introduction to the process of placing sprinklers. The designer will find that selecting sprinklers, placing them, considering uniformity, and giving consideration to soil infiltration rates involves juggling several parameters. The first step in the process is to decide where to locate the sprinklers using the guidelines provided in chapter 3. The next step, deciding on the spacing, involves several factors. First, study the manufacturer's catalogs to see if there are sprinklers available that provide the desired radius of throw. Bear in mind that it is best to stay in the midrange of nozzle sizes and pressures shown in the catalogs. If the desired radius of throw isn't available midrange in the nozzle sizes and/or pressures, consider moving away from the midrange. As pressure goes up, flow goes up. As pressure goes up, radius of throw goes up, but not as fast as flow; therefore, the precipitation rate increases slightly with pressure. It is also important to know the soil classification and the expected infiltration rate. Try to pick a nozzle and pressure that gives a precipitation rate that does not exceed the infiltration rate. If that isn't possible, a cycle and soak strategy may be necessary.

Sizing the Pipelines

There are two procedures used to size pipelines. Generally the delivery pipes within a system are sized by friction loss, and main lines are sized based on velocity. Both systems give similar results, but the thought behind the two methods is that within the delivery system the main concern is pressure drop, whereas in the main line the concern is water velocity that can (and does) result in pressure surges due to water hammer. Consideration of water hammer surges is a more advanced topic, but those interested can find guidance in *Update to Designing, Operating, and Maintaining Piping System Using PVC* located at http://www.irrigation.org/uploadedFiles/Certification/Update%20to%20Designing%20c.pdf.

Friction Factor Method

The friction factor method utilizes the friction loss tables (search for "friction loss charts" at www.irrigation.org) to determine the size of pipe to be used. A partial set of friction loss tables is included in appendix A along with losses through water meters, backflow preventers, and valves. Equation 4-1 and the steps noted are used.

Equation 4-1

$$F_f = P \times \frac{\Delta p}{L}$$

where

F_f = friction factor {psi/100 ft}

P = sprinkler operating pressure at the last sprinkler head on the lateral {psi}

Δp = allowable variation in pressure between the extreme ends of the critical circuit {fraction}

L = critical length of circuit in hundreds of feet [L] is the length over which the allowable pressure variation is measured

The sprinkler operating pressure [P] is the required pressure for the sprinkler to perform correctly. This minimum pressure can be found in the manufacturers' catalogs for the sprinklers used in the design. The variation [Δp] is the allowable variation in pressure between the extreme ends of the critical length of pipe. This value is typically 10 percent but can be as low as 5 percent. The critical length of the circuit [L] is the length of pipe over which the variation is measured. It is expressed in hundreds of feet.

Steps of Pipe Sizing Using the Friction Factor Method

Figure 4-1 demonstrates the use of the friction factor. The following outlines the steps of pipe sizing using the friction factor method.

1. Find the sprinkler operating pressure:
   - Refer to the manufacturer's information on the sprinkler that has been selected to determine the minimum operating pressure to perform at the required flow and radius.
2. Determine the percent variation:
   - Allowable percent variation can be 5 to 10 percent.
   - If lower than normal pressure is available at the water source, the designer may wish to use 5 percent.
3. Calculate the critical length:
   - Determine the worst-case sprinkler on the zone by finding the sprinkler that is the farthest distance from the valve (sprinkler A).
   - Measure the distance the water will have to travel to get from the valve to the worst-case head (L1 + L2).
   - Divide the critical length by 100.

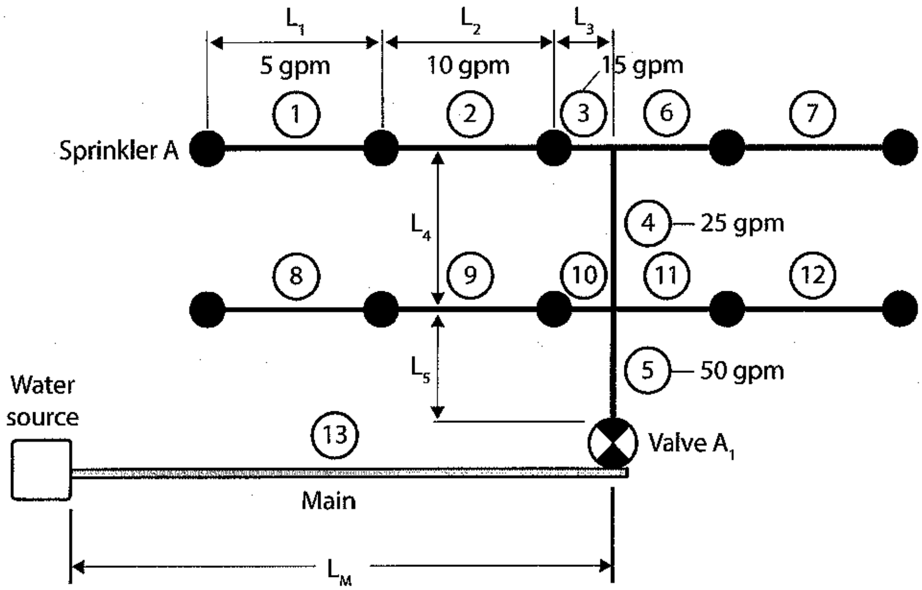


Figure 4-1
Critical lateral and mainline lengths

Example 4-1
Pipe sizing by friction method

For the following conditions, find the allowable friction loss per 100 feet of pipe.

- The minimum sprinkler pressure [P] is determined to be 35 psi.
- The allowable pressure variation [Δp] is 10 percent.
- The critical length is measured to be 145 feet.
- $L_1 = L_2 = 40$ feet
- $L_3 = 5$ feet
- $L_4 = 40$ feet
- $L_5 = 20$ feet

Solution:

$$F_f = \frac{35 \times 0.10}{\left(\frac{145}{100}\right)} = \frac{3.5}{1.45} = 2.41 \text{ psi / 100 ft}$$

Therefore, the designer will select pipe sizes that do not exceed 2.41 psi per 100 feet, regardless of the flow. In doing so, the total pressure loss in the critical length will be no more than 3.5 psi.

A spreadsheet has been developed for sizing pipe using either the friction factor method or the velocity method and can be found on the IA website at www.irrigation.org under Resources/Tools and Calculators.

The solution for example 4-1 using the spreadsheet is shown in figure 4-2. Flow per sprinkler was assumed to be 5 gpm and polyvinyl chloride [PVC] Class 200 pipe was used.

				friction			velocity	friction	
pipe leg number	flow in leg {gpm}	pipe type	length of leg {ft}	based pipe size	velocity {ft/s}	friction loss {psi}	based pipe nom	based pipe nom	max friction {psi}
1	5	CLS 200	40	¾	2.46	0.53	¾	¾	0.97
2	10	CLS 200	40	1	2.99	0.57	¾	1	0.97
3	15	CLS 200	5	1¼	2.79	0.05	1	1¼	0.12
4	25	CLS 200	40	1½	3.53	0.50	1¼	1½	0.97
5	50	CLS 200	20	2	4.50	0.30	2	2	0.48
	Total length		145	Total loss		1.95	Allowed loss		3.50

Figure 4-2
Pipe sizing, friction method

Velocity Method

The velocity method is primarily used for main line sizing and simply involves selecting the smallest pipe for the flow that results in velocity less than 5 feet per second. It can be used in the distribution network, but it will give different results. If it is used for example 4-1, the total loss exceeds 10 percent of the system pressure. Those results are shown in figure 4-3.

				velocity			velocity	friction	
pipe leg number	flow in leg {gpm}	pipe type	length of leg {ft}	based pipe size	velocity {ft/s}	friction loss {psi}	based pipe nom	based pipe nom	max friction {psi}
1	5	CLS 200	40	¾	2.46	0.53	¾	¾	0.97
2	10	CLS 200	40	¾	4.93	1.92	¾	1	0.97
3	15	CLS 200	5	1	4.48	0.15	1	1¼	0.12
4	25	CLS 200	40	1¼	4.64	0.97	1¼	1½	0.97
5	50	CLS 200	20	2	4.50	0.30	2	2	0.48
	Total length		145	Total loss		3.87	Allowed loss		3.50

Figure 4-3
Pipe sizing, velocity method

The pipe sizes selected by the spreadsheet are shown side by side in both figures in columns 8 and 9, but the friction loss calculations apply only to the method noted in the fifth column.

Friction Loss in Fittings, Valves, and Other Devices

It is very important to consider the friction loss in all the components of the system. Losses occur in the service line, water meter, backflow preventer, delivery line, valves, and fittings. The general procedure for determining the pressure needed is based on the worst-case sprinkler. The worst-case sprinkler is the one with greatest total losses to it. It might be in the zone with the greatest flow, the most distant sprinkler, or the highest, or it could be one that has a combination of these factors. The pressure needed is the sprinkler operating pressure plus losses to it plus elevation pressure loss. Or, the pressure at the worst-case sprinkler is the pressure available less all the losses. A system pressure loss worksheet is included in appendix B.

Friction Loss Guidelines

Guidelines for total friction loss in a sprinkler distribution system are not set firmly, but designers should generally comply with the following:

- Total friction loss from the point of connection [POC] to worst-case sprinkler should not exceed one-third of pressure at POC.
- Pressure difference in any zone should not exceed 10 percent of average pressure in the zone.
- Velocity should not exceed 5 feet per second in PVC or polyethylene pipe.
- Loss in water meter should not exceed 10 percent of pressure at POC.

Looped Mains and Submains

At times it may be advantageous to loop main lines or submains. A looped pipeline is one where the end of the line ties back onto itself giving the water two possible pathways of flow. While it will probably take more length of pipe for a looped system, the size of pipe needed will be reduced and will likely result in cost savings. Calculating the friction loss becomes more complex. A good starting point is to assume that the flow splits in half at the point where the pipe is looped. The actual midpoint is near where the flow in each side of the loop is equal, but the length of pipe involved in each flow segment affects how the water flows. Nonetheless, if flow is assumed to be split and calculations are based on half the flow in each side of the loop, the results will be reasonably close to reality. Some sources suggest keeping the same size pipe throughout the loop, but that isn't essential.

Pressure Regulation

If there is enough elevation difference in a zone so that it is difficult to maintain pressure in the zone within 10 percent of the average pressure, pressure regulators may be needed. In reality a pressure regulator is simply a pressure reducer. Good pressure regulators will reduce the pressure to the preset regulator within a few percent. This means that the system must be designed so that the preset regulator pressure is not less than the sprinkler with the least pressure. The regulators will reduce the pressure on all other sprinklers to this pressure. The advantage is that if the pressure is controlled and nozzles have been properly selected and installed, flow from each sprinkler will be very close to the same. The flow difference is roughly half the pressure difference for pressure differences less than about 50 percent.

Example 4-2
Flow difference estimation

In a zone where the minimum pressure sprinkler is at 50 psi and the maximum is 65, the flow difference by the estimation method described above is

$$\frac{1}{2}\left[\frac{(65-50)}{50}\right] = \frac{1}{2}\left(\frac{15}{50}\right) = 0.15 \text{ or } 15\%$$

By actual calculation,

$$\frac{Q}{Q_0} = \sqrt{\frac{P}{P_0}} = \sqrt{\frac{65}{50}} = 1.14 \text{ or a difference of } 14\%$$

Some manufacturers claim accuracy of regulators within 6 percent of preset pressure (so flow difference would be 6% ÷ 2, or 3%), so use of regulators in this example would reduce the flow difference from 14 percent to 3 percent. Regulators are available for installation in the pipeline, and many sprinklers are available with built-in regulators.

Check Valves and Low Head Drainage

In systems with elevation differences within zones, water will drain from the distribution line out the lowest head unless prevented by a check valve. These check valves prevent low head drainage and keep the pipe full of water so that spray operation begins almost immediately when the zone is activated. Sprinklers and sprays are available with low head check valves installed.

Chapter
5

Irrigated Soils

Soils are very important in plant growth and irrigation. They serve as an anchor for the plant and are the main source of water and nutrients for the plant. Furthermore, about half of the total plant is in the soil in the form of roots. The soil serves as a reservoir for water, and when the reservoir gets low, irrigation is necessary. Water entry into the soil and how water is held and moves in soil are very important aspects of the soil/water interaction.

Soil Texture

Soil texture is the term used to define the degree of fineness of the soil, and it is determined by the relative percentages of sand, silt, and clay. The United States Department of Agriculture [USDA] system defines 12 textural classes. Soils are more generally referred to as coarse, medium, and fine. For irrigation purposes, it is adequate to describe soils in the basic three classes with two intermediate classes (moderately fine and moderately coarse).

Following the thought that five basic textural classifications of soils is adequate for most irrigation situations, table 5-1 lists the five soils and representative textural classes as shown in the Natural Resources Conservation Service's [NRCS] *National Engineering Handbook*, Part 652 Irrigation Guide. The five general classes including coarse, moderately coarse, medium, moderately fine, and fine contain specific soil types as shown in table 5-1.

General description	Textural class
Coarse	Sand, loamy sand
Moderately coarse	Sandy loam
Medium	Loam, silt loam, silt
Moderately fine	Clay loam, sandy clay loam, silty clay loam
Fine	Sandy clay, silty clay, clay

Table 5-1
Soils descriptions listed in increasing clay content and decreasing sand content

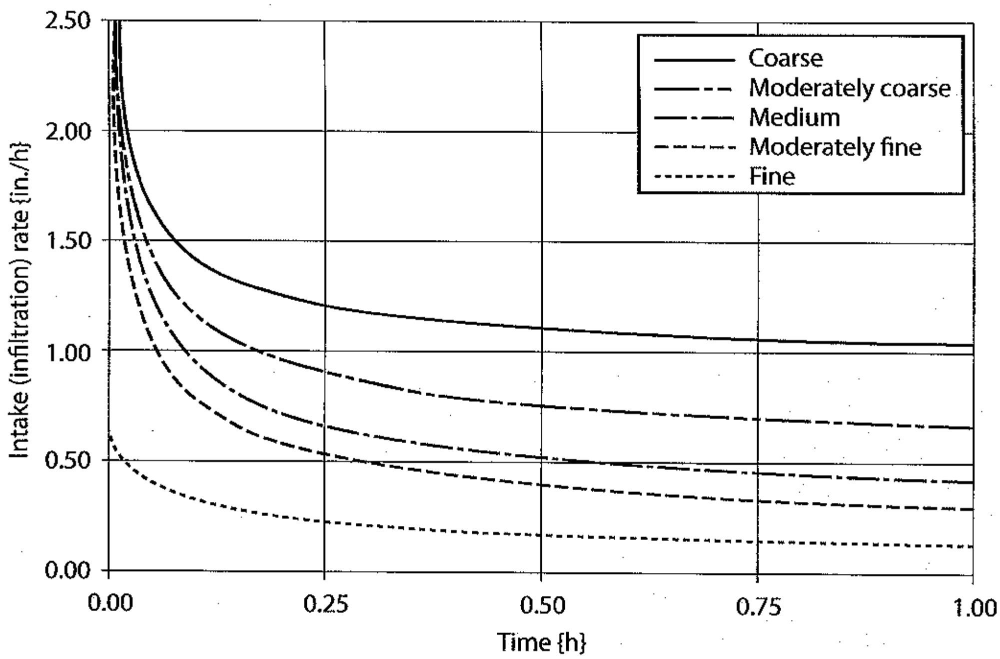
Important Soil Properties

The following two soil properties are the most important in irrigation: intake (infiltration) rate and soil moisture-holding capacity.

Soil Intake Rate (Infiltration Rate)

The rate at which water enters the soil is known as the infiltration or intake rate. It is highly variable over time depending upon soil cover, organic matter, compaction, and tillage. The intake rate of a soil starts high when it is relatively dry and decreases as water is added. The basic intake rate — the rate at which it is nearly stable over time — depends mostly on soil texture. While the combinations of textures are nearly infinite, five general soil classifications represent most soils. The intake rates of these five soils are shown in figure 5-1.

Figure 5-1
Infiltration (intake) rates of five representative soils



Soil Moisture-Holding Capacity and Soil Moisture Extraction

The force it takes to remove water from the soil is dependent upon the moisture content. When the soil is dry, water is very difficult to remove. When it is wet, it freely drains for a short period of time. The relationship between the internal pressure (matric potential) and moisture content of a soil is shown as a soil moisture release curve. Figure 5-2 shows the release curves for five representative soils.

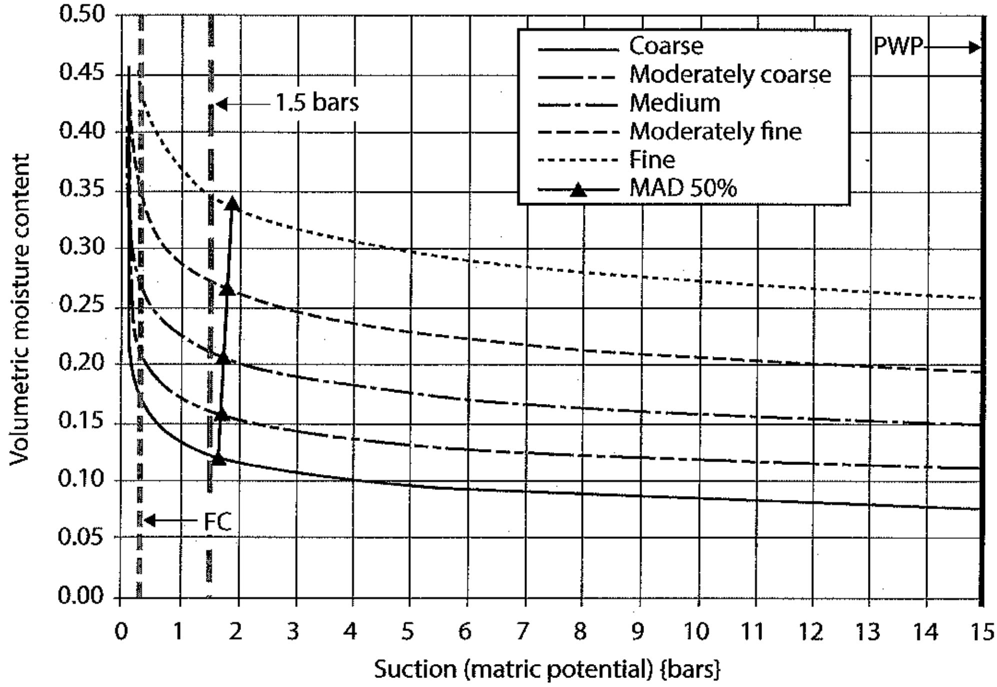


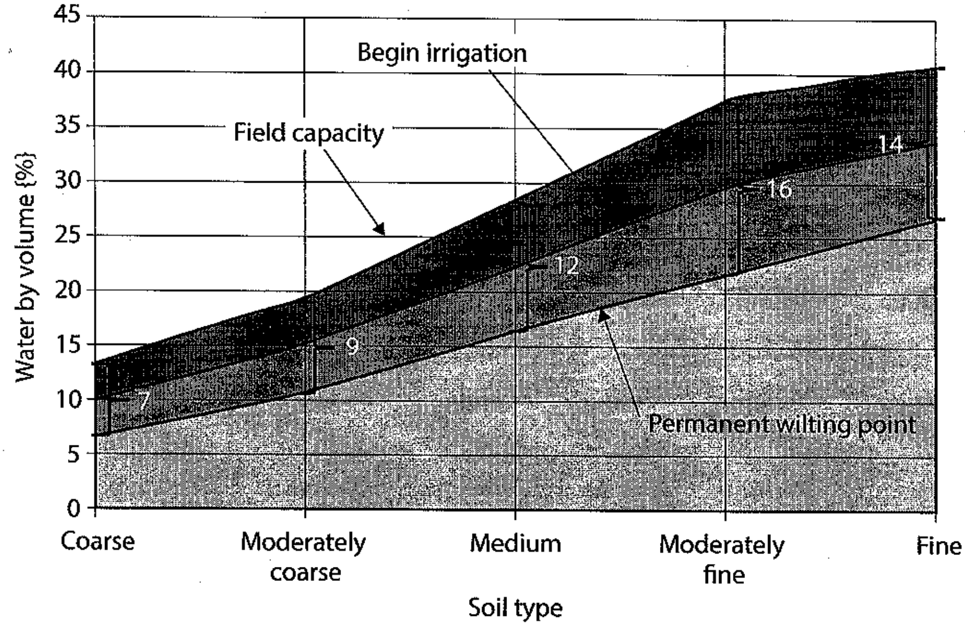
Figure 5-2
Soil moisture release curves — five representative soils

At very low moisture content, water is tightly held by the soil and cannot be removed by the plant. This leads to wilting of the leaves; if the condition is allowed to continue, permanent wilting will occur. The permanent wilting point [PWP] varies with the plant, but it is commonly accepted to be 15 bars (atmospheres). On the other end of the wetting spectrum, water that has entered the soil due to irrigation or rainfall has to be held against gravity or it will drain out. The point at which drainage stops, generally accepted to occur somewhere around 24 hours after the soil has been saturated, occurs at between 0.1 and 0.33 bars, but it is dependent upon the soil. The water content after this drainage has occurred is known as field capacity [FC].

Plants are able to extract water up to 15 bars, but growth conditions for the plant are not optimal if the matric potential is more than about 1.5 bars. For management purposes, the available water in the soil is generally assumed to be the difference between the PWP and FC. However, recognizing that growth is inhibited above 1.5 bars, the readily available water [RAW] is generally described to be from FC to halfway between FC and PWP. Data is readily available for most soils for FC and PWP. To avoid soil moisture conditions that could result in inhibiting growth, irrigators make a management decision to irrigate when about 50 percent of the RAW has been used. This management decision is known as the management allowed depletion [MAD]. The 50 percent MAD line for the five representative soils is also shown in figure 5-2. While it does occur at slightly above 1.5 bars for these five soils, it will not cause significant plant growth inhibition.

The available moisture in a soil is the water that is held between field capacity and permanent wilting point. It is typically shown as a percent by volume or in inches of water per foot of soil. Figure 5-3 shows the available soil moisture as a percent by volume.

Figure 5-3
Available water for representative soils



Representative Soil Characteristics

Table 5-2 summarizes the important soil characteristics used in irrigation system design and management. These characteristics are generalized for the five soil textural classifications and are intended as guidelines.

Table 5-2
Representative soils and key characteristics

Soil*	Infiltration (intake) rate (in./h)	Volumetric water content (VWC)		Moisture-holding capacity (in./ft)
		Field capacity (FC)	Permanent wilting point (PWP)	
Coarse	1.00	0.14	0.07	0.8
Moderately coarse	0.50	0.19	0.10	1.1
Medium	0.40	0.28	0.16	1.4
Moderately fine	0.15	0.36	0.20	1.9
Fine	0.10	0.41	0.27	1.7

* For soil textural classifications, see table 5-1.

Readily Available Water

Water that is not readily available to the plant is retained in the root zone. The forces the plant must overcome to remove water can become very strong, and while the plant may be able to remove some water at high total potential, it cannot remove it fast enough to sustain growth. The problem may be further complicated by salts in the soil that increase the forces to overcome. An electrical conductivity [EC] of 1.4 raises the total potential by 0.5 bars, an EC of 2.8 raises it by 1.0 bar, and an EC of 4.2 precludes any water from being readily available. The term management allowed depletion [MAD] is meant to describe the portion of the total available water that can be readily removed by the plant. MAD is generally accepted to be 50 percent. Readily available water [RAW] is calculated by the following equation.

$$RAW = AW \times \frac{MAD}{100}$$

Equation 5-1

where

RAW = readily available water {in./in., in./ft}
AW = available water {in./in., in./ft}
MAD = management allowed depletion {%}

Water Available to Plants

The water available to plants depends upon the RAW and the depth of the root zone [RZ]. The term plant available water [PAW] refers to the total depth of water readily available to the plant by its roots and is calculated as follows.

$$PAW = AW \times RZ$$

Equation 5-2

where

PAW = plant available water {in.}
AW = available water {in./in., in./ft}
RZ = root zone depth {in., ft}

Designing Irrigation Systems for Soil Conditions

Matching Infiltration (Intake) Rate

Irrigation systems should be designed to match soil conditions. Of primary importance is matching the system precipitation rate to the soil intake rate. If the precipitation rate exceeds the intake rate, runoff can occur. If runoff occurs, the water does not end up where it is supposed to be, and irrigation efficiency suffers. If it isn't possible to design the system for a precipitation rate less than the soil intake rate, a cycle and soak strategy is required as described in chapter 3.

Utilizing Soil Moisture-Holding Capacity

Good irrigation system design and management takes advantage of the soil's ability to store water. The intent of irrigation is to maintain optimum growing conditions for the plants, so excessive water and inadequate water conditions should be avoided. The system should not apply more water than the soil will hold. That depends on both the precipitation rate and the amount of time the system is run. The system should apply water before soil moisture tension (matric potential) exceeds 1.5 bars. The time between irrigations is controlled by the soil moisture-holding capacity and the rate at which the plant uses water, also referred to as landscape evapotranspiration [ET_L]. It is a good practice to not completely fill the soil profile with water thereby allowing room for precipitation, but on coarse soils it may not be practical to not fill the profile because it would require light and frequent irrigation.

Chapter 6

System Operation

It is essential that the designer keep in mind how the system will be operated. Will the system be operated manually, or will it be fully automatic? Will the system adjust for seasonal evapotranspiration changes and/or rain? Will any adjustments be necessary on the equipment such as pressure regulation or manually inserted sprinklers?

Water on Target

The first consideration is that the system be designed and built so that the water goes on target. That is the basic reason that landscape systems are designed "outside-in." The outside-in approach allows water right up to the edge of hardscape or buildings without putting water on them. The second consideration is that the system must be regularly "maintained" to ensure that nozzles work properly, there aren't leaks, and that the arcs of operation are set properly.

Estimate Water Use

Landscape water use typically is estimated by evapotranspiration. Landscape evapotranspiration [ET_L] can be estimated by a variety of means including estimation from weather parameters using a method such as the Penman-Monteith equation. This requires input of temperature, solar radiation, humidity, and wind. There are services that supply ET_L data on a regional basis, or ET_L could be estimated from historical data. Whatever the source, it is important to recognize that water use varies with the season.

$$ET_L = ET_o \times K_L$$

Equation 6-1

where

ET_L = landscape ET {in.}
ET_o = reference ET {in.}
K_L = landscape coefficient

Landscape Coefficient

The landscape coefficient [K_L] is used to adjust reference ET to more appropriately estimate specific plant or turf water needs in the landscape. The concept originated in California but is adapted to be used in other parts of the country. The simplified version presented uses either a turf or plant factor and estimates vegetation density and the influence of microclimate to estimate the amount of water that should be applied to the landscape. This approach helps create an irrigation schedule. Because of the complexity of many landscapes with wide varieties of plants and microclimates on the site, a landscape water manager should consider additional factors that influence plant water usage.

The landscape coefficient is determined by equation 6-2a or 6-2b.

Equation 6-2a

$$K_L = K_T \times K_d \times K_{mc}$$

or

Equation 6-2b

$$K_L = K_P \times K_d \times K_{mc}$$

where

K_L = landscape coefficient
K_T = turf factor
K_P = plant factor
K_d = vegetation density factor
K_{mc} = microclimate factor

Tables 6-1 and 6-2 give ranges of plant water usage that have been created for use by those who have a limited background in irrigation or landscape water management. These tables are based on a more complete explanation found in *Irrigation, Sixth Edition* chapter 5 in the section "Evapotranspiration Coefficients for Landscapes." The methodology presented is the compilation of research and studies from experts to help estimate landscape water requirements for irrigation scheduling.

Turf or Plant Factors

While a considerable amount of research has been done on many of the common varieties of grasses used for turf, most of the values used for crop coefficients have been for well-maintained turfgrass and not for the wide range of grasses that are used in many different types of landscapes. For other landscape plants, water-use research has been very limited; therefore, it is difficult to provide accurate species factors that should be used. Local information can be used if it is available and if the designer understands how the data can be used to appropriately estimate landscape water usage.

To use the turf factor [K_T] or plant factor [K_P], the designer will need to make a subjective judgment about the overall quality of the hydrozone being irrigated. The vast majority of landscapes such as those around nice homes or commercial buildings can be described as "traditional." An example of a "high performance" landscape would be a sports field that requires optimal turf health and appearance. A "low maintenance" landscape would describe the area along the perimeter of a large industrial area or roadway. Some projects could have a combination of all of these general landscape requirements, and the designer must take this into account when estimating plant water usage.

The values listed in table 6-1 will help create an irrigation schedule for turfgrass areas. Note that grasses will use water at different rates throughout the growing season. The actual crop coefficient for grasses by month is often supplied by extension offices where the research data are available. Table 6-1 should be considered the average for the growing season, and it is useful in creating irrigation design but not necessarily appropriate for managing the grass the entire season. The designer can use these values to create a basic schedule, but it is up to the landscape or irrigation manager to modify irrigation schedules to match turf or landscape water demand on a week-to-week basis.

Table 6-1
K_T for turfgrass in a variety of applications

Grass type	High performance (lush)	Acceptable appearance	Low maintenance (lean and green)
Cool season	0.80–0.85	0.70–0.75	0.60–0.65
Warm season	0.70–0.75	0.60–0.65	0.50–0.55

When considering other plants used in the landscape, the designer should make notes about the overall appearance of the landscape and the overall value of the plantings to the landscape (see table 6-2). Healthy plants provide numerous environmental, ecological, and social benefits in the urban environment. As they mature, the water usage changes and should be accounted for when designing a microirrigation system.

Table 6-2
K_p for plants in various landscape applications

Plant type	Maximum appearance	Acceptable appearance	Low maintenance
Trees	0.90–0.95	0.70–0.75	0.45–0.50
Shrubs	0.60–0.65	0.45–0.50	0.30–0.35
Desert plants	0.40–0.45	0.30–0.35	0.20–0.25
Ground cover	0.70–0.80	0.50–0.60	0.30–0.40
Mixed (trees, shrubs, ground cover)	0.90–1.00	0.75–0.80	0.50–0.55

Vegetation Density

Landscape vegetation has both functional use and aesthetic value, and both must be considered in irrigation design and management. However, there may be wide differences in spacing and maturity of plants leading to significant differences in vegetation density. Vegetation density [K_d] refers to the collective leaf area of the plants covering or shading an area of ground. More densely growing vegetation will have higher transpiration rates and require more water than a recently planted landscape. The density factor will be higher for the more mature landscape. A newly installed landscape bed may have only 25 percent of the ground shaded by vegetation. However, an identical landscape bed with the same plants that are 10 years old could have

90 percent of the ground shaded and would require more water than the new planting. Table 6-3 shows density factors for different sizes of plants and for the fraction of ground shaded by the plants when the sun is at noon.

Table 6-3
K_d for landscape plants

Plant type	¼ to ½ ground shaded	½ to ⅔ ground shaded	More than ¾ ground shaded
Low-growing plants < 15" tall	0.35–0.45	0.60–0.75	0.80–0.95
Small shrubs ≈ 3'–4' tall	0.35–0.50	0.70–0.80	0.85–0.95
Large shrubs, trees > 12' tall	0.40–0.55	0.75–0.95	0.95–1.00
Turfgrass	n/a	n/a	1.00

Microclimates

In the urban setting, numerous microclimates [K_{mc}] affect plant water usage. Common sense indicates that plants growing in the shade use less water than the same plant growing in full sun. A hot environment with plantings along a south-facing brick wall or in parking lot islands surrounded by paved surfaces and car exhaust will increase the water demand by plants. The designer must estimate the influence of the microclimate on the hydrozone. Because reference ET is based on measuring weather data in a large open field of an actively growing crop in full sun, the influence of microclimate is considered to be 1.0. Table 6-4 can be used as a guide when estimating the influence of microclimates in landscape settings.

Table 6-4
K_{mc} for various exposures

Vegetation	High	Average (reference conditions)	Low
Turfgrass/landscape plants	1.2–1.4	1.0	0.5–0.8

Calculating Landscape Water Requirements

The following equation can be used to determine the peak water requirement based on area irrigated, ET_L, landscape coefficient, and the irrigation application efficiency. The flow rate is in gallons for the period of time that ET_L has been estimated.

Equation 6-3

$$Q = \frac{A \times ET_o \times K_L \times 0.623}{E_a} = \frac{A \times ET_L \times 0.623}{E_a}$$

where

Q = gallons of water for a period of time such as a day or week
A = canopy area of plant × 0.75 for applying water to 75% of the area {ft^2}
ET_o = peak ET for a specific period such as day or week
K_L = landscape coefficient
0.623 = conversion to gallons
E_a = irrigation application efficiency
0.85 for hot, arid climate
0.90 for moderate climate
0.95 for cool climate
ET_L = landscape water requirement for the specific period = $ET_o \times K_L$

Minimize Water Losses

Good operation and management of the system goes beyond designing the system well and managing it for actual ET_L. Wind can cause the irrigation water to drift off the target, and when possible, irrigation should be avoided during windy conditions. Furthermore, under low relative humidity and high temperature, irrigation water will evaporate more readily. The time of day with the lowest wind, lowest temperature, and highest relative humidity is likely just before dawn, so if irrigation can be scheduled at that time of day, it will lead to the best efficiency. One significant disadvantage to irrigating in the predawn hours is that if there is a malfunction of the system, it is unlikely that the owner or operator will see it and take corrective action. Wind sensors are available that can be incorporated into the system to prevent operation in high wind.

Allow for Rainfall

Allowing for rainfall means that the system should not be run during a rainfall event, and, if possible, there should be adequate soil moisture-holding capacity to allow the rain to be captured in the soil rather than having it deep percolate or run off. Sensors are available that prevent system operation during rainfall events, but allowing soil moisture-holding capacity for rain involves active and careful management.

Chapter 7

Sensors, Control Devices, and Smart Control

Smart Water Application Technologies [SWAT] is a national partnership initiative of water purveyors and irrigation industry representatives created to promote landscape water use efficiency through the application of state-of-the-art irrigation technologies. "Smart" irrigation technologies are changing the face of landscape irrigation.

SWAT

IA has developed an independent third-party testing protocol specific to smart climatologically based controllers. Currently the protocol is administered through the Center for Irrigation Technology, an independent testing laboratory, applied research facility, and educational resource center based at California State University, Fresno. The objective of this protocol is to evaluate how well current commercial technology has integrated the scientific data into a practical system that meets the agronomic needs of turf and landscape plants.

Each product evaluation is conducted by creating a six-zone virtual landscape subjected to a real-time climate through monitoring of a selected weather station to evaluate the ability of individual smart controllers to adequately and efficiently irrigate that landscape.

After initial programming and calibration, the controller is expected to perform without further intervention during the test period. Performance results indicate to what degree the controller maintained root zone moistures within an acceptable range:

- If moisture levels are maintained without deficit, it can be assumed that the level of irrigation will be adequate to maintain the health and beauty of the landscape.
- If moisture levels are maintained without excess, it can be assumed that scheduling maximizes water-use efficiency.

SWAT Definition of Smart Controller

Smart controllers estimate or measure depletion of available plant soil moisture in order to operate an irrigation system, replenishing water as needed while minimizing excess water use. A properly programmed smart controller requires initial site-specific setup and will make irrigation schedule adjustments, including run times and required cycles, throughout the irrigation season without human intervention.

Testing of Smart Controllers

IA test performance reports for smart controllers are a record of the water applied by a properly installed and programmed smart controller without human intervention for a testing period that receives a minimum ET of 2.5 inches and a minimum rainfall of 0.4 inches.

Use of Smart Controllers

For best results when using a smart controller, incorporate proper hydraulic design and equipment layout in the irrigation system installation. Initial monitoring of the site is necessary to confirm the accuracy of the irrigation schedule. Maintenance issues and site modifications may require irrigation system repair or recalibration of the smart controller settings to optimize system performance.

WaterSense Labeling Program

In 2006, the Environmental Protection Agency [EPA] created a national program called the WaterSense program to promote water efficiency similar to Energy Star for energy efficiency. In 2012, EPA's WaterSense labeling program began listing weather-based irrigation controllers. While the EPA's WaterSense labeling criteria for weather-based controllers are based on SWAT's most current testing protocol, it is important to note that the two protocols are not identical, and they are administered separately. The WaterSense program labels products without providing the results from the tests to the consumer. The label is given if the product has at least 80 percent irrigation adequacy and less than 10 percent excess irrigation for any particular landscape zone with less than 5 percent excess averaged for all irrigation zones.

Weather-Based Controller Specifications

The EPA WaterSense specification criteria modified the SWAT testing protocol as follows:

- minimum run times: All run times (irrigation cycles) that occur during the test period must be greater than 3 minutes in duration.
- missing data from the reference weather station: Provisions are provided for missing reference evapotranspiration [ET_o] and rainfall data but no more than 3 days in total during the test period.
- rainfall requirement: There shall be at least 4 individual days during the test period with 0.10 inches or greater of gross rainfall for the test to be considered valid.

- order of operations to calculate the water balance: The order of operations implemented by the EPA WaterSense program shall be crop evapotranspiration [ET_c], irrigation, and then rainfall. (This differs from the order as designated in the SWAT protocol where it is ET_c, rainfall, and then irrigation — to maximize the benefit of natural precipitation.)

Commercial Versions of Smart Controllers

The following provides further information about commercial versions of smart controllers:

- controllers that store historical ET_c data characteristic of the site
- controllers that utilize on-site sensors as a basis for calculating real time ET_c
- controllers that utilize a central weather station as a basis for ET_c calculations and to transmit the data to individual homeowners from remote sites
- controllers that utilize on-site rainfall and temperature sensors
- control technology that is added on to existing time-based controllers

Using Smart Controllers

Before using smart controllers, it is important to review the definition of a smart controller. They can be climate-based, sensor-based, or dependent on add-on devices. Smart controllers *estimate* or *measure* depletion of soil moisture. That information is then used to control the irrigation system, replenishing water as needed but without excess water use. The SWAT protocol defines adequate as meeting ET_L (at least 80 percent of ET_L), and excess as more than 105 percent of ET_L. In this case, the crop is assumed to be the landscape, so $ET_L = ET_c$.

The definition further states the following: A properly programmed smart controller requires initial site-specific setup and will make irrigation schedule adjustments, including run times and required cycles, throughout the irrigation season without human intervention.

Two aspects of this definition are critical. First, the setup must be site specific. Second, the controller must make schedule adjustments without human intervention. That means that the controller is using whatever sensing or historical data is available to change the irrigation schedule appropriately, which includes rainfall events.

Sensors

Rain Sensors

A wide variety of sensors can be interfaced with many controllers. The most common is a rain sensor, and the most common of those is one with disks that expand when wet and interrupt the electrical circuit to turn on the valves. These devices are simple, inexpensive, and reasonably reliable.

Wind Sensors

Wind sensors are used less often but interface with the controller to provide additional information used in calculating ET. Simpler ones are available that interrupt the electrical signal to valves to prevent irrigating in high wind conditions.

Freeze Sensors

This sensor interrupts the system to prevent irrigation when temperatures are below freezing. It is often combined with a rain sensor.

Flow Sensors

These sensors are designed to interrupt the electrical signal to valves if excess flow is detected. They are used to protect from flooding when a sprinkler or pipe is damaged.

Solar Sensors

Solar radiation is a key factor in ET calculations, and this sensor supplies solar radiation to a controller capable of calculating ET.

Soil Sensors

Soil sensors provide information regarding the soil moisture. They can be integrated into controllers capable of processing the input, or simpler ones can be used to interrupt the electrical signal to valves when the soil is too wet for irrigation.

An in-depth discussion of soil moisture sensors can be found in *Irrigation, Sixth Edition.* Soil moisture can be measured either directly or indirectly, but almost all modern devices are indirect methods. Table 7-1 shows a variety of methods with respective advantages and disadvantages. Users are strongly advised to carefully review the characteristics of the device especially as it relates to resolution, the need for calibration, and whether the device is affected by temperature, soil salinity, or close contact with soil particles.

Integrated Weather Sensors

These devices include several sensors needed for ET calculations and can be added on to controllers capable of processing weather data.

Table 7-1
Advantages and disadvantages of soil moisture monitoring devices

	Advantages	Disadvantages
Direct gravimetric/ volumetric	• Easy	• Destructive, time-consuming, and labor-consuming
Neutron probe	• Accurate • Large number of measurements	• Expensive and heavy instrument; safety hazard (neutron and emitted gamma radiation); requires training and radiation badge • Requires calibration, manual, and long readings • Unsuitable for detection of moisture profile discontinuity (i.e., wetting front or boundaries between soil layers) and for measurements near soil surface
TDR	• Accurate, normally no calibration required • Minimal soil disturbance • Simultaneous measurements	• Relatively expensive • Limited applicability in saline soils • Limited use because of probes
FD probes	• Better resolution than TDR • Can be connected to data logger • Relatively inexpensive	• Requires calibration • Needs good contact with soil
ADR probes	• Minimal soil disturbance, can be connected to data logger • Inexpensive	• Requires calibration • Affected by air gaps, stones, or preferential flow
Tensiometer	• Direct reading • Continuous reading possible • Well suited for irrigation scheduling • Inexpensive • Minimum maintenance skill required	• Needs good contact with soil • Limited soil matric potential range (< 1 bar) • Relatively slow response time • Contact between ceramic cup and soil can become loose • Requires frequent maintenance
Gypsum block/ granular matrix block	• Simple and inexpensive • Requires no maintenance • Continuous reading possible • Well suited for irrigation scheduling	• Low resolution; block properties change with time • Relatively slow reaction time; not suitable for swelling soils and for measurements around soil saturation • Temperature-dependent; inaccurate readings due to hysteresis
Soil psychrometer	• High sensitivity • Suitable for very dry soil conditions	• Very slow reaction time • Low accuracy in wet range • Specialized equipment required for sensor reading • Small sensing volume • Not recommended at shallow depths

Chapter
8

Management and Maintenance

Good irrigation system operation depends on having a good design, proper installation, good management, and good maintenance. This manual takes the reader through the important design concepts involving uniformity, spacing, and pressure. It points out the significance of matching the system to the soil and plant water needs and provides insight as to how the system should be operated and how advanced sensors and controllers might be used. However, the system will not achieve the ultimate goal of efficient use of water if it is not properly managed and maintained. Once the system has been designed and installed, the user has no choice but to manage it as best as possible. A great design and proper installation is of no value if the system isn't properly managed. However, great management cannot overcome poor design or installation.

Management: Apply the Proper Amount of Water

Applying the proper amount of water is first and foremost in system management. Determining the proper amount of water depends on the situation, but the following should be considered.

Replace Water Used

The irrigation system needs to replace the water used. The amount of water used can be estimated by several means and measured by other means. Estimation methods include measuring key weather parameters and estimating water use from these parameters. The most widely used estimation method is the Penman-Monteith equation that was discussed in chapter 6. Some areas have ET estimation services provided by private or state agencies. Soil moisture sensors can provide data on the amount of water remaining in the soil and hence lead to how much was used and when irrigation should be started.

Determine Irrigation Frequency

Irrigation frequency is set by the soil moisture-holding capacity, water use rate, and management allowed depletion [MAD]. However, local agencies may limit the number of days on which irrigation may occur, and MAD is based on soils and allowing soil moisture-holding capacity for rain. In the absence of rain and agency constraints, irrigation frequency only depends on soil moisture-holding capacity and ET. Allowing room for rainfall changes the irrigation strategy in that the irrigation cycle should begin at MAD, but the profile would not be filled.

Cycle and Soak

A further consideration in irrigation frequency arises when the intake rate of the soil is less than the precipitation rate. This leads to cycle and soak as described in chapter 3.

Smart Controllers

Smart controllers were discussed in chapter 7. A smart controller is capable of changing the irrigation frequency, but a good manager must monitor its performance.

Check the Results

A good manager checks the performance of the irrigation system. Two methods give good information about the system performance.

Plant Appearance and Longevity

In most cases, the appearance of the plant material and its longevity are the primary goals of the system. Good management requires constant monitoring of the appearance of the plant material and maintenance of records to know the longevity of plants.

Audit the System Performance

The irrigation system should be observed and audited for proper performance. Often, pressure issues in the system can be detected merely by observing the system operating. Broken sprinklers, plugged or blown out nozzles, leaking pipes, and improperly operating valves are the most common causes of system pressure issues.

Monitor Key System Parameters

Pressure and flow rate are the two most important parameters to monitor in system performance. Devices are available to report pressure of flow outside a set of limits, and similar devices are available to shut the system off if the parameters are outside the limits. These devices are uncommon on residential systems, but the owner or operator can simply observe the system operation during the cycles and determine whether the pressure and flow are within limits. Many systems do not have flow meters, so observing pressure may be the only option. Every irrigation system should have a pressure gauge installed in an easily observed location.

Adjust to Local Conditions

Local conditions (weather, area irrigated, local supply pressure, etc.) may require adjusting the system operation.

Account for Nonuniformity

The primary means of accounting for nonuniformity in a sprinkler system is to adjust the run time to minimize the area receiving inadequate water. This means that the average amount of water applied is more than needed to meet ET_L. As a result, some is wasted and efficiency goes down. No system is perfectly uniform, so it is important to decide whether some overwatering is necessary, as well as how much. In part, it depends on whether the areas being underwatered are next to each other. As water is applied to the surface, it naturally redistributes as it moves down in the soil and tends to get more uniform. If the underwatered areas aren't adjacent to each other, then the redistribution in the soil may take care of some of the underwatering. Furthermore, many grasses on many different soils do not require the full amount of irrigation. How much less than full irrigation to apply is a management decision, and how much of the area to underirrigate is another management decision. The effect of these decisions can be seen by observing a destination diagram for an audit of a system.

Destination Diagrams

Figure 8-1 shows a destination diagram for a sample area. It is assumed that any spot receiving less than 80 percent of the average (average is set to adequate) is inadequately watered, and any area receiving more than 120 percent of the average is excessively watered. The destination diagram and the accompanying analysis (spreadsheet available on the IA website at www.irrigation.org under Resources/Tools and Calculators) show that the DU_{lq} is 0.73. With a scheduling multiplier of 1.0, the maximum possible efficiency is 91 percent, 16 percent of the area is excessively watered (more than 120 percent of average), 44 percent is overwatered (more than average), 53 percent is underwatered (less than average), and 19 percent is inadequately watered.

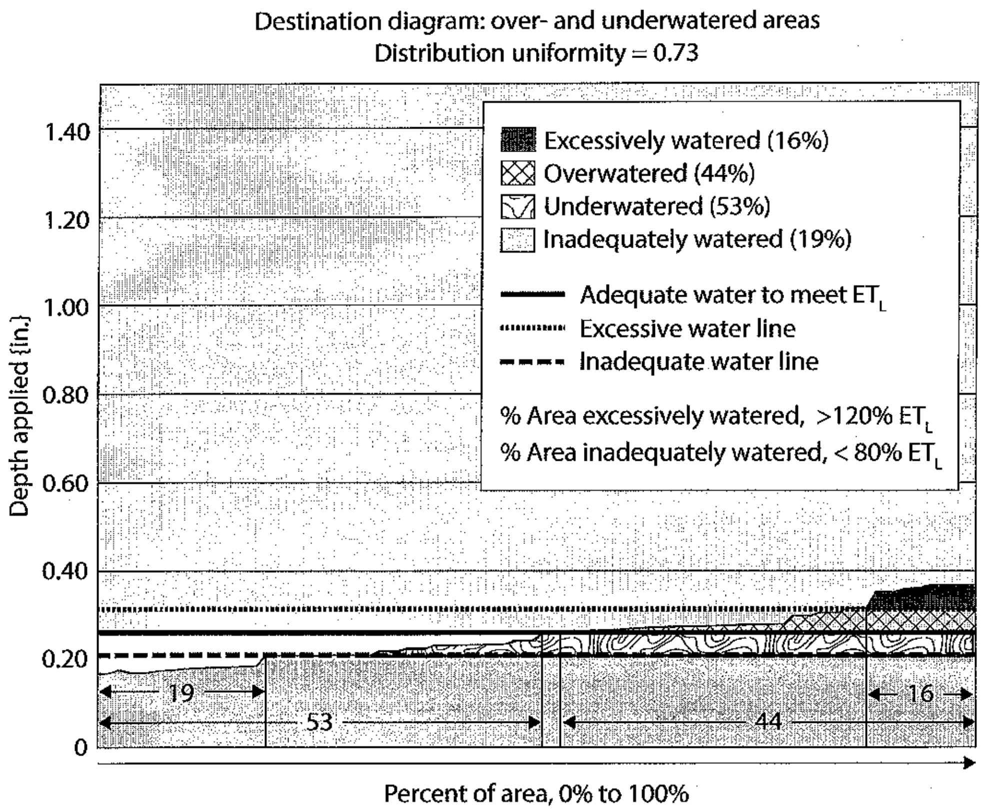


Figure 8-1
Destination diagram—over- and underwatered areas

If the decision had been made to increase the run time with a run time multiplier of 1.19 (upper boundary) as suggested by the DU_{lq}, the results would be as follows:

- maximum possible efficiency: 79 percent
- excessively watered: 63 percent
- overwatered: 78 percent
- underwatered: 19 percent
- inadequately watered: none

However, it could be that 75 percent of the average water is adequate for meeting plant appearance and longevity goals. Some also consider that anything over 105 percent of average is excessive, so changing those values gives the following when using a run time multiplier of 1.0:

- excessively watered: 38 percent
- overwatered: 47 percent
- underwatered: 50 percent
- inadequately watered: 19 percent
- maximum possible efficiency: 91 percent

Choosing the upper limit for the run time gives the following:

- excessively watered: 66 percent
- overwatered: 78 percent
- underwatered: 19 percent
- inadequately watered: none

Adequate Watering and Run Time

There is considerable national discussion on what constitutes adequate watering. For the sake of looking at management decisions without entering the national discussion, assume that less than 80 percent ET_L is inadequately watered, and more than 120 percent of ET is excessively watered. Now the effect of changing run time on efficiency and overwatering can be better explored.

Contiguous Area

As previously discussed, the soil tends to redistribute the applied water, and if the dry areas aren't contiguous as shown in the example in figures 2-4, 2-5, and 2-6, it is possible that having 10 percent of the area underwatered is acceptable. Then, the question is, "What is the appropriate run time leading to 10 percent of the area being underwatered?" It is a run time multiplier more than 1.0 and less than 1.19. A few tries with the Audit_Sched_Mgr spreadsheet leads to a run time multiplier of 1.14. That results in the following:

- excessively watered: 50 percent
- overwatered: 59 percent
- underwatered: 38 percent
- inadequately watered: 9 percent
- efficiency: 84 percent

This demonstrates the use of the spreadsheet to evaluate watering strategies.

Adequate Watering and Excessively Overwatering Trade-off

The previous example should make it clear that any attempt to compensate for non-uniformity by increasing run time in order to prevent an inadequately watered area results in an excessively overwatered area and a decrease in efficiency.

Achieving 100 Percent Efficiency

Occasionally the question arises as to whether it is possible to achieve 100 percent efficiency without having 100 percent uniformity. The answer is yes, but the results may not be acceptable. Efficiency is defined as the fraction of water applied that ends up being used by the plant. It is assumed that water applied in excess of plant needs ends up as deep percolation and is lost for plant use. So, it is possible to achieve 100 percent efficiency on any system. If the run time is reduced until the area receiving the most water just reaches what is defined as adequate, then 100 percent efficiency is achieved, as all water applied is available for plant use. Using the same system as previously shown, the destination diagram for 100 percent efficiency is shown in figure 8-2. A run time multiplier of 0.70 leads to these results. The problem here is that while no area is overwatered, 100 percent is underwatered. The big problem is that 78 percent is inadequately watered (80 percent of ET_L), and no doubt dry areas will be visible and shorter lived. It shows that 53 percent of the area receives less than 70 percent of ET_L, 34 percent receives less than 60 percent of ET_L, and 16 percent receives less than 50 percent of ET_L.

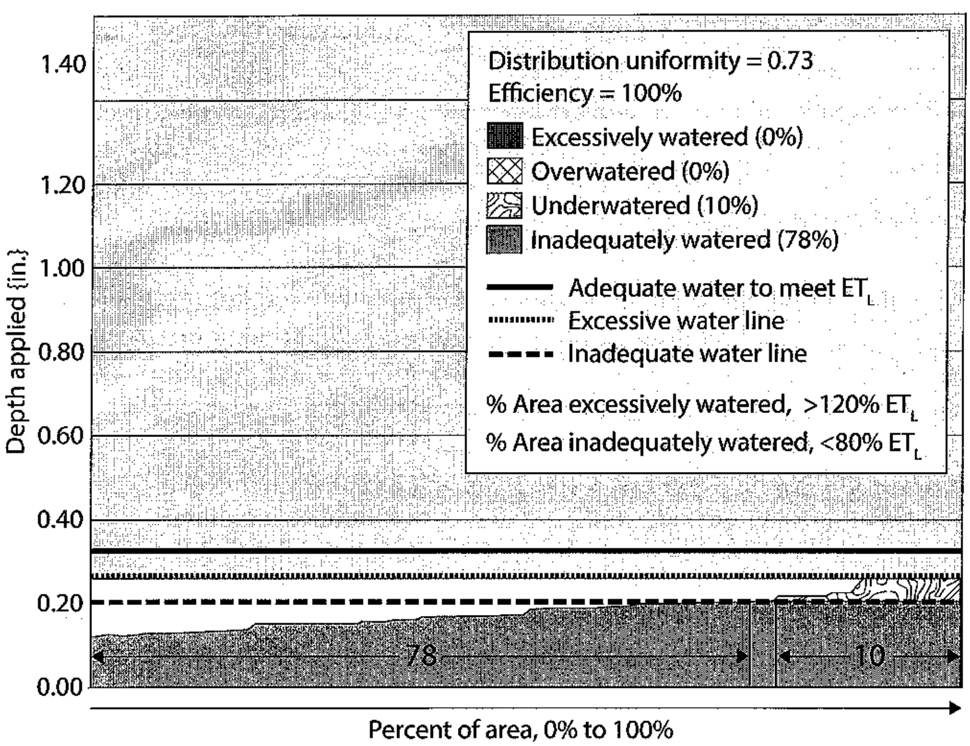


Figure 8-2
Destination diagram for 100 percent efficiency

Maintain the System

Check the system pressure regularly to ensure that adequate pressure is being supplied from the point of connection to the last sprinkler or emitter. Look for excessive pressure drop in valves, fittings, and other components.

Winterize the System

A major consideration of any maintenance program is preparing the system for winter. A poor program will jeopardize the longevity of the irrigation system. Proper winterizing starts with understanding the complete workings of the system, especially how it is designed. The objective of winterizing is the removal of the majority of water from the mainline and lateral pipe. Since many agronomists recommend keeping turfgrass areas wet prior to the first freeze, this means keeping the system operational until the first freeze. Occasionally, light freezes that may cause damage to exposed piping will be encountered. Make sure the night temperatures are monitored, and drain exposed lines where necessary. Water left in the pipes, valves, fittings, and sprinklers may expand and cause severe damage. Removing the water can be accomplished by one or more methods: gravity drain, air pressure blowout, and sump pumping.

Winterize the Controllers

Check all field controllers to make sure they are winterized. Many manufacturers suggest removal of the controllers and batteries from the field during the winter. Have the controllers tested and serviced if necessary. If the controllers are left in the field, disconnect all input and output wiring. This will eliminate damage that could be caused by lightning over the winter. Some controller manufacturers recommend leaving controllers running over the winter to minimize condensation buildup, especially manufacturers of electromechanical controllers.

Maintenance work that can be performed on the system in the winter should be done at this time. This minimizes the field problems in the spring when the system is started for the first time of the year. Consult the manufacturer's specific recommendations regarding servicing the controller grounding connections and wire.

Annually Check System Components

All system components should be checked for proper operation at least annually. Proper operation includes checking for leaks, proper opening and popping up, proper nozzle operation (not plugged, not blown out, not leaking), proper pressure, and correct arc adjustment. It is a good idea to flow check questionable sprinklers and audit a region where performance appears problematic.

Appendix
A

Friction Loss Charts

Irrigation Association

Friction Loss Charts 2008

Tables are based upon the following Hazen-Williams Equation:

$$H_f = 0.2083 \times \left(\frac{100}{C}\right)^{1.852} \times \frac{Q^{1.852}}{D^{4.866}}$$

The result is multiplied by 0.433 to give pounds per square inch {psi} loss for 100 feet of pipe.

The velocity values were derived using the following equation:

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

The average inside diameter of outside diameter [OD] controlled pipe was based upon subtracting two times the minimum wall thickness plus one-half of the wall thickness tolerance from the outside diameter.

Information for pipe diameters and wall thicknesses came from the following resources:

- *ASABE Standards*. 2007. ANSI/ASAE S376.2 — Design, Installation and Performance of Underground, Thermoplastic Irrigation Pipes
- *Handbook of PVC Pipe*. Uni-Bell PVC Pipe Association
- Appropriate ASTM standards for nonplastic pipes

Pressure ratings for plastic pipes are based on 23°C or 73.4°F.

Head loss decreases (increases) approximately 1 percent for every 3 degrees Fahrenheit above (below) the reference temperature (73.4°F).

Irrigation Association Friction Loss Chart 2008

Class 160 PVC IPS Plastic Pipe

ANSI/ASAE S376.2 ASTM D2241 SDR 26 C=150

psi loss per 100 feet of pipe

	Shown for convenience																			
Nominal	Class 315		Class 200																	
size	1/2"		3/4"		1"		1-1/4"		1-1/2"		2"		2-1/2"		3"		4"		6"	
Avg. ID	0.696		0.910		1.175		1.512		1.734		2.173		2.635		3.210		4.134		6.084	
Pipe OD	0.840		1.050		1.315		1.660		1.900		2.375		2.875		3.500		4.500		6.625	
Avg. wall	0.072		0.070		0.070		0.074		0.083		0.101		0.120		0.145		0.183		0.271	
Min. wall	0.062		0.060		0.060		0.064		0.073		0.091		0.110		0.135		0.173		0.255	
Flow (gpm)	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss
1	0.84	0.25	0.49	0.07	0.30	0.02	0.18	0.01	0.14	0.00										
2	1.68	0.90	0.99	0.24	0.59	0.07	0.36	0.02	0.27	0.01	0.17	0.00								
3	2.53	1.90	1.48	0.52	0.89	0.15	0.54	0.04	0.41	0.02	0.26	0.01								
4	3.37	3.24	1.97	0.88	1.18	0.25	0.71	0.07	0.54	0.04	0.35	0.01	0.24	0.00						
5	4.21	4.89	2.46	1.33	1.48	0.38	0.89	0.11	0.68	0.06	0.43	0.02	0.29	0.01						
6	5.05	6.86	2.96	1.86	1.77	0.54	1.07	0.16	0.81	0.08	0.52	0.03	0.35	0.01	0.24	0.00				
7	5.90	9.12	3.45	2.47	2.07	0.71	1.25	0.21	0.95	0.11	0.60	0.04	0.41	0.01	0.28	0.01				
8	6.74	11.68	3.94	3.17	2.36	0.91	1.43	0.27	1.09	0.14	0.69	0.05	0.47	0.02	0.32	0.01				
9	7.58	14.53	4.43	3.94	2.66	1.14	1.61	0.33	1.22	0.17	0.78	0.06	0.53	0.02	0.36	0.01				
10	8.42	17.66	4.93	4.79	2.96	1.38	1.78	0.40	1.36	0.21	0.86	0.07	0.59	0.03	0.40	0.01				
12	10.11	24.75	5.91	6.71	3.55	1.94	2.14	0.57	1.63	0.29	1.04	0.10	0.71	0.04	0.48	0.01				
14	11.79	32.93	6.90	8.93	4.14	2.58	2.50	0.76	1.90	0.39	1.21	0.13	0.82	0.05	0.55	0.02				
16	13.48	42.16	7.88	11.44	4.73	3.30	2.86	0.97	2.17	0.50	1.38	0.17	0.94	0.06	0.63	0.02	0.38	0.01		
18	15.16	52.44	8.87	14.23	5.32	4.10	3.21	1.20	2.44	0.62	1.56	0.21	1.06	0.08	0.71	0.03	0.43	0.01		
20			9.85	17.29	5.91	4.99	3.57	1.46	2.71	0.75	1.73	0.25	1.18	0.10	0.79	0.04	0.48	0.01		
22			10.84	20.63	6.50	5.95	3.93	1.74	2.99	0.90	1.90	0.30	1.29	0.12	0.87	0.04	0.53	0.01		
24			11.82	24.24	7.09	6.99	4.28	2.05	3.26	1.05	2.07	0.35	1.41	0.14	0.95	0.05	0.57	0.02		
26			12.81	28.11	7.68	8.11	4.64	2.38	3.53	1.22	2.25	0.41	1.53	0.16	1.03	0.06	0.62	0.02		
28			13.80	32.25	8.27	9.30	5.00	2.73	3.80	1.40	2.42	0.47	1.65	0.18	1.11	0.07	0.67	0.02		
30			14.78	36.64	8.87	10.57	5.35	3.10	4.07	1.59	2.59	0.53	1.76	0.21	1.19	0.08	0.72	0.02		
32					9.46	11.91	5.71	3.49	4.34	1.79	2.76	0.60	1.88	0.23	1.27	0.09	0.76	0.03	0.35	0.00
34					10.05	13.32	6.07	3.91	4.61	2.01	2.94	0.67	2.00	0.26	1.35	0.10	0.81	0.03	0.37	0.00
36					10.64	14.81	6.42	4.34	4.88	2.23	3.11	0.74	2.12	0.29	1.43	0.11	0.86	0.03	0.40	0.00
38					11.23	16.37	6.78	4.80	5.16	2.46	3.28	0.82	2.23	0.32	1.50	0.12	0.91	0.04	0.42	0.01
40					11.82	18.00	7.14	5.28	5.43	2.71	3.46	0.90	2.35	0.35	1.58	0.14	0.95	0.04	0.44	0.01
42					12.41	19.70	7.50	5.78	5.70	2.97	3.63	0.99	2.47	0.39	1.66	0.15	1.00	0.04	0.46	0.01
44					13.00	21.47	7.85	6.30	5.97	3.23	3.80	1.08	2.59	0.42	1.74	0.16	1.05	0.05	0.48	0.01
46					13.59	23.32	8.21	6.84	6.24	3.51	3.97	1.17	2.70	0.46	1.82	0.18	1.10	0.05	0.51	0.01
48					14.18	25.23	8.57	7.40	6.51	3.80	4.15	1.27	2.82	0.50	1.90	0.19	1.15	0.06	0.53	0.01
50					14.78	27.21	8.92	7.98	6.78	4.10	4.32	1.37	2.94	0.53	1.98	0.20	1.19	0.06	0.55	0.01
55							9.82	9.52	7.46	4.89	4.75	1.63	3.23	0.64	2.18	0.24	1.31	0.07	0.61	0.01
60							10.71	11.18	8.14	5.74	5.18	1.91	3.53	0.75	2.38	0.29	1.43	0.08	0.66	0.01
65							11.60	12.97	8.82	6.66	5.62	2.22	3.82	0.87	2.57	0.33	1.55	0.10	0.72	0.01
70							12.49	14.88	9.50	7.64	6.05	2.55	4.11	1.00	2.77	0.38	1.67	0.11	0.77	0.02
75							13.38	16.90	10.18	8.68	6.48	2.89	4.41	1.13	2.97	0.43	1.79	0.13	0.83	0.02
80							14.28	19.05	10.86	9.78	6.91	3.26	4.70	1.28	3.17	0.49	1.91	0.14	0.88	0.02
85									11.53	10.94	7.34	3.65	4.99	1.43	3.37	0.55	2.03	0.16	0.94	0.02
90									12.21	12.16	7.78	4.06	5.29	1.59	3.56	0.61	2.15	0.18	0.99	0.03
95									12.89	13.45	8.21	4.48	5.58	1.76	3.76	0.67	2.27	0.20	1.05	0.03
100									13.57	14.79	8.64	4.93	5.88	1.93	3.96	0.74	2.39	0.22	1.10	0.03
110									14.93	17.64	9.50	5.88	6.46	2.30	4.36	0.88	2.63	0.26	1.21	0.04
120											10.37	6.91	7.05	2.71	4.75	1.04	2.86	0.30	1.32	0.05
130											11.23	8.02	7.64	3.14	5.15	1.20	3.10	0.35	1.43	0.05
140											12.10	9.20	8.23	3.60	5.54	1.38	3.34	0.40	1.54	0.06
150											12.96	10.45	8.81	4.09	5.94	1.57	3.58	0.46	1.65	0.07
160											13.82	11.77	9.40	4.61	6.34	1.76	3.82	0.52	1.76	0.08
170											14.69	13.17	9.99	5.16	6.73	1.97	4.06	0.58	1.87	0.09
180													10.58	5.73	7.13	2.19	4.30	0.64	1.98	0.10
190													11.16	6.34	7.52	2.42	4.54	0.71	2.09	0.11
200													11.75	6.97	7.92	2.67	4.77	0.78	2.20	0.12
220													12.93	8.31	8.71	3.18	5.25	0.93	2.42	0.14
240													14.10	9.77	9.50	3.74	5.73	1.09	2.65	0.17
260															10.29	4.33	6.21	1.27	2.87	0.19
280															11.09	4.97	6.68	1.45	3.09	0.22
300															11.88	5.65	7.16	1.65	3.31	0.25
320															12.67	6.37	7.64	1.86	3.53	0.28
340															13.46	7.12	8.12	2.08	3.75	0.32
360															14.25	7.92	8.59	2.31	3.97	0.35
380																	9.07	2.56	4.19	0.39
400																	9.55	2.81	4.41	0.43
420																	10.03	3.08	4.63	0.47
440																	10.50	3.35	4.85	0.51
460																	10.98	3.64	5.07	0.56
480																	11.46	3.94	5.29	0.60
500																	11.94	4.25	5.51	0.65

Shaded area represents velocities over 5 ft/s. Use with caution.

Irrigation Association Friction Loss Chart 2008

Class 200 PVC IPS Plastic Pipe

ANSI/ASAE S376.2 ASTM D2241 SDR 21 C=150

psi loss per 100 feet of pipe

Nominal size	Shown for convenience Class 315 1/2"		3/4"		1"		1-1/4"		1-1/2"		2"		2-1/2"		3"		4"		6"	
Avg. ID	0.696		0.910		1.169		1.482		1.700		2.129		2.581		3.146		4.046		5.955	
Pipe OD	0.840		1.050		1.315		1.660		1.900		2.375		2.875		3.500		4.500		6.625	
Avg. wall	0.072		0.070		0.073		0.089		0.100		0.123		0.147		0.177		0.227		0.335	
Min. wall	0.062		0.060		0.063		0.079		0.090		0.113		0.137		0.167		0.214		0.316	
Flow {gpm}	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss
1	0.84	0.25	0.49	0.07	0.30	0.02	0.19	0.01	0.14	0.00										
2	1.68	0.90	0.99	0.24	0.60	0.07	0.37	0.02	0.28	0.01	0.18	0.00								
3	2.53	1.90	1.48	0.52	0.90	0.15	0.56	0.05	0.42	0.02	0.27	0.01								
4	3.37	3.24	1.97	0.88	1.19	0.26	0.74	0.08	0.56	0.04	0.36	0.01	0.24	0.01						
5	4.21	4.89	2.46	1.33	1.49	0.39	0.93	0.12	0.71	0.06	0.45	0.02	0.31	0.01						
6	5.05	6.86	2.96	1.86	1.79	0.55	1.11	0.17	0.85	0.09	0.54	0.03	0.37	0.01	0.25	0.00				
7	5.90	9.12	3.45	2.47	2.09	0.73	1.30	0.23	0.99	0.12	0.63	0.04	0.43	0.02	0.29	0.01				
8	6.74	11.68	3.94	3.17	2.39	0.94	1.49	0.30	1.13	0.15	0.72	0.05	0.49	0.02	0.33	0.01				
9	7.58	14.53	4.43	3.94	2.69	1.17	1.67	0.37	1.27	0.19	0.81	0.06	0.55	0.02	0.37	0.01				
10	8.42	17.66	4.93	4.79	2.99	1.42	1.86	0.45	1.41	0.23	0.90	0.08	0.61	0.03	0.41	0.01				
12	10.11	24.75	5.91	6.71	3.58	1.98	2.23	0.63	1.69	0.32	1.08	0.11	0.73	0.04	0.49	0.02				
14	11.79	32.93	6.90	8.93	4.18	2.64	2.60	0.83	1.98	0.43	1.26	0.14	0.86	0.06	0.58	0.02				
16	13.48	42.16	7.88	11.44	4.78	3.38	2.97	1.07	2.26	0.55	1.44	0.18	0.98	0.07	0.66	0.03	0.40	0.01		
18	15.16	52.44	8.87	14.23	5.37	4.21	3.34	1.33	2.54	0.68	1.62	0.23	1.10	0.09	0.74	0.03	0.45	0.01		
20			9.85	17.29	5.97	5.11	3.72	1.61	2.82	0.83	1.80	0.28	1.22	0.11	0.82	0.04	0.50	0.01		
22			10.84	20.63	6.57	6.10	4.09	1.92	3.11	0.99	1.98	0.33	1.35	0.13	0.91	0.05	0.55	0.01		
24			11.82	24.24	7.17	7.17	4.46	2.26	3.39	1.16	2.16	0.39	1.47	0.15	0.99	0.06	0.60	0.02		
26			12.81	28.11	7.76	8.31	4.83	2.62	3.67	1.34	2.34	0.45	1.59	0.18	1.07	0.07	0.65	0.02		
28			13.80	32.25	8.36	9.53	5.20	3.01	3.95	1.54	2.52	0.52	1.71	0.20	1.15	0.08	0.70	0.02		
30			14.78	36.64	8.96	10.83	5.57	3.41	4.24	1.75	2.70	0.59	1.84	0.23	1.24	0.09	0.75	0.03		
32					9.55	12.21	5.94	3.85	4.52	1.97	2.88	0.66	1.96	0.26	1.32	0.10	0.80	0.03	0.37	0.00
34					10.15	13.66	6.32	4.31	4.80	2.21	3.06	0.74	2.08	0.29	1.40	0.11	0.85	0.03	0.39	0.00
36					10.75	15.18	6.69	4.79	5.08	2.45	3.24	0.82	2.20	0.32	1.48	0.12	0.90	0.04	0.41	0.01
38					11.35	16.78	7.06	5.29	5.36	2.71	3.42	0.91	2.33	0.36	1.57	0.14	0.95	0.04	0.44	0.01
40					11.94	18.45	7.43	5.82	5.65	2.98	3.60	1.00	2.45	0.39	1.65	0.15	1.00	0.04	0.46	0.01
42					12.54	20.20	7.80	6.37	5.93	3.27	3.78	1.09	2.57	0.43	1.73	0.16	1.05	0.05	0.48	0.01
44					13.14	22.02	8.17	6.94	6.21	3.56	3.96	1.19	2.69	0.47	1.81	0.18	1.10	0.05	0.51	0.01
46					13.73	23.91	8.55	7.54	6.49	3.86	4.14	1.29	2.82	0.51	1.90	0.19	1.15	0.06	0.53	0.01
48					14.33	25.87	8.92	8.15	6.78	4.18	4.32	1.40	2.94	0.55	1.98	0.21	1.20	0.06	0.55	0.01
50					14.93	27.90	9.29	8.79	7.06	4.51	4.50	1.51	3.06	0.59	2.06	0.23	1.25	0.07	0.58	0.01
55							10.22	10.49	7.76	5.38	4.95	1.80	3.37	0.71	2.27	0.27	1.37	0.08	0.63	0.01
60							11.15	12.33	8.47	6.32	5.40	2.11	3.67	0.83	2.47	0.32	1.50	0.09	0.69	0.01
65							12.07	14.30	9.18	7.33	5.85	2.45	3.98	0.96	2.68	0.37	1.62	0.11	0.75	0.02
70							13.00	16.40	9.88	8.41	6.30	2.81	4.29	1.10	2.89	0.42	1.74	0.12	0.81	0.02
75							13.93	18.63	10.59	9.56	6.75	3.20	4.59	1.25	3.09	0.48	1.87	0.14	0.86	0.02
80							14.86	21.00	11.29	10.77	7.20	3.60	4.90	1.41	3.30	0.54	1.99	0.16	0.92	0.02
85									12.00	12.05	7.65	4.03	5.21	1.58	3.50	0.60	2.12	0.18	0.98	0.03
90									12.71	13.40	8.10	4.48	5.51	1.76	3.71	0.67	2.24	0.20	1.04	0.03
95									13.41	14.81	8.55	4.95	5.82	1.94	3.92	0.74	2.37	0.22	1.09	0.03
100									14.12	16.28	9.00	5.45	6.12	2.13	4.12	0.81	2.49	0.24	1.15	0.04
110											9.90	6.50	6.74	2.55	4.53	0.97	2.74	0.29	1.27	0.04
120											10.80	7.63	7.35	2.99	4.95	1.14	2.99	0.34	1.38	0.05
130											11.70	8.85	7.96	3.47	5.36	1.32	3.24	0.39	1.50	0.06
140											12.60	10.16	8.57	3.98	5.77	1.52	3.49	0.45	1.61	0.07
150											13.50	11.54	9.19	4.52	6.18	1.73	3.74	0.51	1.73	0.08
160											14.40	13.01	9.80	5.10	6.60	1.95	3.99	0.57	1.84	0.09
170													10.41	5.70	7.01	2.18	4.24	0.64	1.96	0.10
180													11.02	6.34	7.42	2.42	4.49	0.71	2.07	0.11
190													11.64	7.01	7.83	2.67	4.74	0.79	2.19	0.12
200													12.25	7.71	8.24	2.94	4.98	0.86	2.30	0.13
220													13.47	9.19	9.07	3.51	5.48	1.03	2.53	0.16
240													14.70	10.80	9.89	4.12	5.98	1.21	2.76	0.18
260															10.72	4.78	6.48	1.41	2.99	0.21
280															11.54	5.48	6.98	1.61	3.22	0.25
300															12.37	6.23	7.48	1.83	3.45	0.28
320															13.19	7.02	7.98	2.06	3.68	0.31
340															14.02	7.86	8.47	2.31	3.91	0.35
360															14.84	8.73	8.97	2.57	4.14	0.39
380																	9.47	2.84	4.37	0.43
400																	9.97	3.12	4.60	0.48
420																	10.47	3.42	4.83	0.52
440																	10.97	3.72	5.06	0.57
460																	11.46	4.04	5.29	0.62
480																	11.96	4.37	5.52	0.67
500																	12.46	4.72	5.75	0.72

Shaded area represents velocities over 5 ft/s. Use with caution.

Irrigation Association Friction Loss Chart 2008

Class 315 PVC IPS Plastic Pipe

ANSI/ASAE S376.2 ASTM D2241 SDR 13.5 C=150
psi loss per 100 feet of pipe

Nominal size	1/2"		3/4"		1"		1-1/4"		1-1/2"		2"		2-1/2"		3"		4"		6"	
Avg. ID	0.696		0.874		1.101		1.394		1.598		1.983		2.423		2.948		3.794		5.583	
Pipe OD	0.840		1.050		1.315		1.660		1.900		2.375		2.875		3.500		4.500		6.625	
Avg. wall	0.072		0.088		0.107		0.133		0.151		0.196		0.226		0.274		0.353		0.521	
Min. wall	0.062		0.078		0.097		0.123		0.141		0.176		0.213		0.259		0.333		0.491	
Flow (gpm)	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss
1	0.84	0.25	0.53	0.08	0.34	0.03	0.21	0.01	0.16	0.00										
2	1.68	0.90	1.07	0.30	0.67	0.10	0.42	0.03	0.32	0.02	0.21	0.01								
3	2.53	1.90	1.60	0.63	1.01	0.20	0.63	0.06	0.48	0.03	0.31	0.01								
4	3.37	3.24	2.14	1.07	1.35	0.35	0.84	0.11	0.64	0.06	0.42	0.02	0.28	0.01						
5	4.21	4.89	2.67	1.61	1.68	0.53	1.05	0.17	0.80	0.09	0.52	0.03	0.35	0.01						
6	5.05	6.86	3.20	2.26	2.02	0.74	1.26	0.23	0.96	0.12	0.62	0.04	0.42	0.02	0.28	0.01				
7	5.90	9.12	3.74	3.01	2.36	0.98	1.47	0.31	1.12	0.16	0.73	0.06	0.49	0.02	0.33	0.01				
8	6.74	11.68	4.27	3.86	2.69	1.25	1.68	0.40	1.28	0.20	0.83	0.07	0.56	0.03	0.38	0.01				
9	7.58	14.53	4.81	4.80	3.03	1.56	1.89	0.49	1.44	0.25	0.93	0.09	0.63	0.03	0.42	0.01				
10	8.42	17.66	5.34	5.83	3.37	1.90	2.10	0.60	1.60	0.31	1.04	0.11	0.69	0.04	0.47	0.02				
12	10.11	24.75	6.41	8.17	4.04	2.66	2.52	0.84	1.92	0.43	1.25	0.15	0.83	0.06	0.56	0.02				
14	11.79	32.93	7.48	10.87	4.71	3.53	2.94	1.12	2.24	0.58	1.45	0.20	0.97	0.08	0.66	0.03				
16	13.48	42.16	8.55	13.92	5.39	4.53	3.36	1.44	2.56	0.74	1.66	0.26	1.11	0.10	0.75	0.04	0.45	0.01		
18	15.16	52.44	9.61	17.32	6.06	5.63	3.78	1.79	2.88	0.92	1.87	0.32	1.25	0.12	0.85	0.05	0.51	0.01		
20			10.68	21.05	6.73	6.84	4.20	2.17	3.20	1.12	2.08	0.39	1.39	0.15	0.94	0.06	0.57	0.02		
22			11.75	25.11	7.40	8.16	4.62	2.59	3.52	1.33	2.28	0.47	1.53	0.18	1.03	0.07	0.62	0.02		
24			12.82	29.50	8.08	9.59	5.04	3.04	3.83	1.57	2.49	0.55	1.67	0.21	1.13	0.08	0.68	0.02		
26			13.89	34.21	8.75	11.12	5.46	3.53	4.15	1.82	2.70	0.64	1.81	0.24	1.22	0.09	0.74	0.03		
28			14.96	39.25	9.42	12.76	5.88	4.05	4.47	2.08	2.91	0.73	1.95	0.27	1.31	0.11	0.79	0.03		
30			16.02	44.60	10.10	14.50	6.30	4.60	4.79	2.37	3.11	0.83	2.08	0.31	1.41	0.12	0.85	0.04		
32					10.77	16.34	6.72	5.18	5.11	2.67	3.32	0.93	2.22	0.35	1.50	0.14	0.91	0.04	0.42	0.01
34					11.44	18.28	7.14	5.80	5.43	2.98	3.53	1.04	2.36	0.39	1.60	0.15	0.96	0.04	0.45	0.01
36					12.12	20.32	7.56	6.45	5.75	3.32	3.74	1.16	2.50	0.44	1.69	0.17	1.02	0.05	0.47	0.01
38					12.79	22.46	7.98	7.13	6.07	3.67	3.94	1.28	2.64	0.48	1.78	0.19	1.08	0.05	0.50	0.01
40					13.46	24.70	8.40	7.84	6.39	4.03	4.15	1.41	2.78	0.53	1.88	0.20	1.13	0.06	0.52	0.01
42					14.14	27.04	8.82	8.58	6.71	4.41	4.36	1.54	2.92	0.58	1.97	0.22	1.19	0.07	0.55	0.01
44					14.81	29.47	9.24	9.35	7.03	4.81	4.57	1.68	3.06	0.63	2.07	0.24	1.25	0.07	0.58	0.01
46					15.48	32.00	9.66	10.15	7.35	5.22	4.77	1.83	3.20	0.69	2.16	0.27	1.30	0.08	0.60	0.01
48					16.16	34.62	10.08	10.98	7.67	5.65	4.98	1.98	3.34	0.75	2.25	0.29	1.36	0.08	0.63	0.01
50					16.83	37.34	10.50	11.85	7.99	6.09	5.19	2.13	3.47	0.80	2.35	0.31	1.42	0.09	0.65	0.01
55							11.55	14.13	8.79	7.27	5.71	2.54	3.82	0.96	2.58	0.37	1.56	0.11	0.72	0.02
60							12.60	16.60	9.59	8.54	6.23	2.99	4.17	1.13	2.82	0.43	1.70	0.13	0.79	0.02
65							13.65	19.26	10.39	9.91	6.74	3.47	4.52	1.31	3.05	0.50	1.84	0.15	0.85	0.02
70							14.70	22.09	11.18	11.37	7.26	3.98	4.86	1.50	3.29	0.58	1.98	0.17	0.92	0.03
75							15.75	25.10	11.98	12.91	7.78	4.52	5.21	1.70	3.52	0.66	2.13	0.19	0.98	0.03
80							16.80	28.29	12.78	14.55	8.30	5.09	5.56	1.92	3.76	0.74	2.27	0.22	1.05	0.03
85									13.58	16.28	8.82	5.70	5.91	2.15	3.99	0.83	2.41	0.24	1.11	0.04
90									14.38	18.10	9.34	6.33	6.25	2.39	4.23	0.92	2.55	0.27	1.18	0.04
95									15.18	20.01	9.86	7.00	6.60	2.64	4.46	1.02	2.69	0.30	1.24	0.05
100									15.98	22.00	10.38	7.70	6.95	2.90	4.69	1.12	2.83	0.33	1.31	0.05
110											11.41	9.18	7.64	3.46	5.16	1.33	3.12	0.39	1.44	0.06
120											12.45	10.79	8.34	4.07	5.63	1.57	3.40	0.46	1.57	0.07
130											13.49	12.51	9.03	4.72	6.10	1.82	3.68	0.53	1.70	0.08
140											14.53	14.35	9.73	5.41	6.57	2.08	3.97	0.61	1.83	0.09
150											15.56	16.31	10.42	6.15	7.04	2.37	4.25	0.69	1.96	0.11
160											16.60	18.38	11.12	6.93	7.51	2.67	4.54	0.78	2.09	0.12
170													11.81	7.76	7.98	2.99	4.82	0.87	2.23	0.13
180													12.51	8.62	8.45	3.32	5.10	0.97	2.36	0.15
190													13.20	9.53	8.92	3.67	5.39	1.08	2.49	0.16
200													13.90	10.48	9.39	4.03	5.67	1.18	2.62	0.18
220													15.29	12.50	10.33	4.81	6.24	1.41	2.88	0.22
240													16.68	14.69	11.27	5.66	6.80	1.66	3.14	0.25
260															12.21	6.56	7.37	1.92	3.40	0.29
280															13.15	7.52	7.94	2.20	3.67	0.34
300															14.08	8.55	8.50	2.50	3.93	0.38
320															15.02	9.64	9.07	2.82	4.19	0.43
340															15.96	10.78	9.64	3.16	4.45	0.48
360															16.90	11.98	10.20	3.51	4.71	0.54
380																	10.77	3.88	4.97	0.59
400																	11.34	4.27	5.24	0.65
420																	11.90	4.67	5.50	0.71
440																	12.47	5.09	5.76	0.78
460																	13.04	5.53	6.02	0.84
480																	13.61	5.98	6.28	0.91
500																	14.17	6.45	6.54	0.98

Shaded area represents velocities over 5 ft/s. Use with caution.

Irrigation Association Friction Loss Chart 2008

Schedule 40 PVC IPS Plastic Pipe

ASTM D1785 C=150
psi loss per 100 feet of pipe

Nominal size	1/2"		3/4"		1"		1-1/4"		1-1/2"		2"		2-1/2"		3"		4"		6"	
Avg. ID	0.602		0.804		1.029		1.360		1.590		2.047		2.445		3.042		3.998		6.031	
Pipe OD	0.840		1.050		1.315		1.660		1.900		2.375		2.875		3.500		4.500		6.625	
Avg. wall	0.119		0.123		0.143		0.150		0.155		0.164		0.215		0.229		0.251		0.297	
Min. wall	0.109		0.113		0.133		0.140		0.145		0.154		0.203		0.216		0.237		0.280	
Flow (gpm)	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss
1	1.13	0.50	0.63	0.12	0.39	0.04	0.22	0.01	0.16	0.00										
2	2.25	1.82	1.26	0.44	0.77	0.13	0.44	0.03	0.32	0.02	0.19	0.00								
3	3.38	3.85	1.89	0.94	1.16	0.28	0.66	0.07	0.48	0.03	0.29	0.01								
4	4.50	6.55	2.52	1.60	1.54	0.48	0.88	0.12	0.65	0.06	0.39	0.02	0.27	0.01						
5	5.63	9.91	3.16	2.42	1.93	0.73	1.10	0.19	0.81	0.09	0.49	0.03	0.34	0.01						
6	6.75	13.89	3.79	3.40	2.31	1.02	1.32	0.26	0.97	0.12	0.58	0.04	0.41	0.02	0.26	0.01				
7	7.88	18.48	4.42	4.52	2.70	1.36	1.54	0.35	1.13	0.16	0.68	0.05	0.48	0.02	0.31	0.01				
8	9.01	23.66	5.05	5.79	3.08	1.74	1.76	0.45	1.29	0.21	0.78	0.06	0.55	0.03	0.35	0.01				
9	10.13	29.43	5.68	7.20	3.47	2.17	1.99	0.56	1.45	0.26	0.88	0.08	0.61	0.03	0.40	0.01				
10	11.26	35.77	6.31	8.75	3.85	2.63	2.21	0.68	1.61	0.32	0.97	0.09	0.68	0.04	0.44	0.01				
12	13.51	50.14	7.57	12.27	4.62	3.69	2.65	0.95	1.94	0.44	1.17	0.13	0.82	0.05	0.53	0.02				
14	15.76	66.71	8.84	16.32	5.39	4.91	3.09	1.26	2.26	0.59	1.36	0.17	0.96	0.07	0.62	0.03				
16	18.01	85.42	10.10	20.90	6.17	6.29	3.53	1.62	2.58	0.76	1.56	0.22	1.09	0.09	0.71	0.03	0.41	0.01		
18	20.26	106.24	11.36	25.99	6.94	7.82	3.97	2.01	2.90	0.94	1.75	0.28	1.23	0.12	0.79	0.04	0.46	0.01		
20			12.62	31.59	7.71	9.51	4.41	2.45	3.23	1.14	1.95	0.33	1.36	0.14	0.88	0.05	0.51	0.01		
22			13.89	37.69	8.48	11.35	4.85	2.92	3.55	1.37	2.14	0.40	1.50	0.17	0.97	0.06	0.56	0.02		
24			15.15	44.28	9.25	13.33	5.29	3.43	3.87	1.60	2.34	0.47	1.64	0.20	1.06	0.07	0.61	0.02		
26			16.41	51.36	10.02	15.46	5.74	3.98	4.20	1.86	2.53	0.54	1.77	0.23	1.15	0.08	0.66	0.02		
28			17.67	58.91	10.79	17.73	6.18	4.56	4.52	2.13	2.73	0.62	1.91	0.26	1.23	0.09	0.71	0.02		
30			18.94	66.94	11.56	20.15	6.62	5.19	4.84	2.42	2.92	0.71	2.05	0.30	1.32	0.10	0.77	0.03		
32					12.33	22.71	7.06	5.85	5.16	2.73	3.12	0.80	2.18	0.34	1.41	0.12	0.82	0.03	0.36	0.00
34					13.10	25.41	7.50	6.54	5.49	3.06	3.31	0.89	2.32	0.38	1.50	0.13	0.87	0.03	0.38	0.00
36					13.87	28.24	7.94	7.27	5.81	3.40	3.51	0.99	2.46	0.42	1.59	0.14	0.92	0.04	0.40	0.01
38					14.64	31.22	8.38	8.04	6.13	3.76	3.70	1.10	2.59	0.46	1.68	0.16	0.97	0.04	0.43	0.01
40					15.41	34.33	8.82	8.84	6.46	4.13	3.89	1.21	2.73	0.51	1.76	0.18	1.02	0.05	0.45	0.01
42					16.18	37.58	9.26	9.67	6.78	4.52	4.09	1.32	2.87	0.56	1.85	0.19	1.07	0.05	0.47	0.01
44					16.95	40.96	9.71	10.54	7.10	4.93	4.28	1.44	3.00	0.61	1.94	0.21	1.12	0.06	0.49	0.01
46					17.73	44.47	10.15	11.45	7.42	5.35	4.48	1.57	3.14	0.66	2.03	0.23	1.17	0.06	0.52	0.01
48					18.50	48.12	10.59	12.39	7.75	5.79	4.67	1.69	3.28	0.71	2.12	0.25	1.23	0.07	0.54	0.01
50					19.27	51.90	11.03	13.36	8.07	6.25	4.87	1.83	3.41	0.77	2.20	0.27	1.28	0.07	0.56	0.01
55							12.13	15.94	8.88	7.45	5.36	2.18	3.75	0.92	2.42	0.32	1.40	0.08	0.62	0.01
60							13.24	18.72	9.68	8.75	5.84	2.56	4.09	1.08	2.65	0.37	1.53	0.10	0.67	0.01
65							14.34	21.72	10.49	10.15	6.33	2.97	4.44	1.25	2.87	0.43	1.66	0.11	0.73	0.02
70							15.44	24.91	11.30	11.65	6.82	3.41	4.78	1.43	3.09	0.50	1.79	0.13	0.79	0.02
75							16.54	28.31	12.10	13.23	7.30	3.87	5.12	1.63	3.31	0.56	1.91	0.15	0.84	0.02
80							17.65	31.90	12.91	14.91	7.79	4.36	5.46	1.84	3.53	0.63	2.04	0.17	0.90	0.02
85									13.72	16.69	8.28	4.88	5.80	2.06	3.75	0.71	2.17	0.19	0.95	0.03
90									14.52	18.55	8.76	5.43	6.14	2.29	3.97	0.79	2.30	0.21	1.01	0.03
95									15.33	20.50	9.25	6.00	6.48	2.53	4.19	0.87	2.42	0.23	1.07	0.03
100									16.14	22.55	9.74	6.59	6.82	2.78	4.41	0.96	2.55	0.25	1.12	0.03
110											10.71	7.87	7.51	3.31	4.85	1.14	2.81	0.30	1.23	0.04
120											11.68	9.24	8.19	3.89	5.29	1.34	3.06	0.36	1.35	0.05
130											12.66	10.72	8.87	4.52	5.73	1.56	3.32	0.41	1.46	0.06
140											13.63	12.30	9.55	5.18	6.17	1.79	3.57	0.47	1.57	0.06
150											14.61	13.97	10.24	5.89	6.61	2.03	3.83	0.54	1.68	0.07
160											15.58	15.75	10.92	6.63	7.05	2.29	4.08	0.61	1.79	0.08
170													11.60	7.42	7.50	2.56	4.34	0.68	1.91	0.09
180													12.28	8.25	7.94	2.85	4.59	0.75	2.02	0.10
190													12.97	9.12	8.38	3.15	4.85	0.83	2.13	0.11
200													13.65	10.03	8.82	3.46	5.11	0.92	2.24	0.12
220													15.01	11.96	9.70	4.13	5.62	1.09	2.47	0.15
240													16.38	14.06	10.58	4.85	6.13	1.28	2.69	0.17
260															11.46	5.63	6.64	1.49	2.92	0.20
280															12.35	6.46	7.15	1.71	3.14	0.23
300															13.23	7.34	7.66	1.94	3.37	0.26
320															14.11	8.27	8.17	2.19	3.59	0.30
340															14.99	9.25	8.68	2.45	3.81	0.33
360															15.87	10.29	9.19	2.72	4.04	0.37
380																	9.70	3.01	4.26	0.41
400																	10.21	3.31	4.49	0.45
420																	10.72	3.62	4.71	0.49
440																	11.23	3.95	4.94	0.53
460																	11.74	4.28	5.16	0.58
480																	12.25	4.64	5.38	0.63
500																	12.76	5.00	5.61	0.68
Working pressure	600 psi		480 psi		450 psi		370 psi		330 psi		300 psi		280 psi		260 psi		220 psi		180 psi	

Shaded area represents velocities over 5 ft/s.
Use with caution.

Irrigation Association Friction Loss Chart 2008

Schedule 80 PVC IPS Plastic Pipe

ASTM D1785 C=150

psi loss per 100 feet of pipe

Nominal size	1/2"		3/4"		1"		1-1/4"		1-1/2"		2"		2-1/2"		3"		4"		6"	
Avg. ID	0.526		0.722		0.935		1.254		1.476		1.913		2.289		2.864		3.786		5.709	
Pipe OD	0.840		1.050		1.315		1.660		1.900		2.375		2.875		3.500		4.500		6.625	
Avg. wall	0.157		0.164		0.190		0.203		0.212		0.231		0.293		0.318		0.357		0.458	
Min. wall	0.147		0.154		0.179		0.191		0.200		0.218		0.276		0.300		0.337		0.432	
Flow (gpm)	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss
1	1.47	0.97	0.78	0.21	0.47	0.06	0.26	0.01	0.19	0.01										
2	2.95	3.50	1.57	0.75	0.93	0.21	0.52	0.05	0.37	0.02	0.22	0.01								
3	4.42	7.42	2.35	1.59	1.40	0.45	0.78	0.11	0.56	0.05	0.33	0.01								
4	5.90	12.64	3.13	2.71	1.87	0.77	1.04	0.18	0.75	0.08	0.45	0.02	0.31	0.01						
5	7.37	19.11	3.91	4.09	2.33	1.16	1.30	0.28	0.94	0.13	0.56	0.04	0.39	0.01						
6	8.85	26.78	4.70	5.74	2.80	1.63	1.56	0.39	1.12	0.18	0.67	0.05	0.47	0.02	0.30	0.01				
7	10.32	35.63	5.48	7.63	3.27	2.17	1.82	0.52	1.31	0.24	0.78	0.07	0.55	0.03	0.35	0.01				
8	11.80	45.63	6.26	9.77	3.73	2.78	2.08	0.67	1.50	0.30	0.89	0.09	0.62	0.04	0.40	0.01				
9	13.27	56.75	7.04	12.15	4.20	3.45	2.34	0.83	1.69	0.37	1.00	0.11	0.70	0.04	0.45	0.01				
10	14.75	68.98	7.83	14.77	4.67	4.20	2.59	1.01	1.87	0.46	1.11	0.13	0.78	0.05	0.50	0.02				
12			9.39	20.70	5.60	5.88	3.11	1.41	2.25	0.64	1.34	0.18	0.93	0.08	0.60	0.03				
14			10.96	27.55	6.53	7.83	3.63	1.88	2.62	0.85	1.56	0.24	1.09	0.10	0.70	0.03				
16			12.52	35.27	7.47	10.03	4.15	2.40	3.00	1.09	1.78	0.31	1.25	0.13	0.80	0.04	0.46	0.01		
18			14.09	43.87	8.40	12.47	4.67	2.99	3.37	1.35	2.01	0.38	1.40	0.16	0.90	0.05	0.51	0.01		
20			15.65	53.32	9.33	15.16	5.19	3.63	3.75	1.64	2.23	0.47	1.56	0.19	0.99	0.07	0.57	0.02		
22					10.27	18.08	5.71	4.33	4.12	1.96	2.45	0.56	1.71	0.23	1.09	0.08	0.63	0.02		
24					11.20	21.24	6.23	5.09	4.49	2.30	2.68	0.65	1.87	0.27	1.19	0.09	0.68	0.02		
26					12.13	24.64	6.75	5.91	4.87	2.67	2.90	0.76	2.02	0.32	1.29	0.11	0.74	0.03		
28					13.07	28.26	7.26	6.77	5.24	3.06	3.12	0.87	2.18	0.36	1.39	0.12	0.80	0.03		
30					14.00	32.12	7.78	7.70	5.62	3.48	3.34	0.99	2.34	0.41	1.49	0.14	0.85	0.04		
32					14.93	36.19	8.30	8.68	5.99	3.92	3.57	1.11	2.49	0.46	1.59	0.16	0.91	0.04	0.40	0.01
34					15.87	40.49	8.82	9.71	6.37	4.39	3.79	1.24	2.65	0.52	1.69	0.17	0.97	0.04	0.43	0.01
36							9.34	10.79	6.74	4.88	4.01	1.38	2.80	0.58	1.79	0.19	1.02	0.05	0.45	0.01
38							9.86	11.93	7.12	5.40	4.24	1.53	2.96	0.64	1.89	0.21	1.08	0.06	0.48	0.01
40							10.38	13.11	7.49	5.93	4.46	1.68	3.11	0.70	1.99	0.24	1.14	0.06	0.50	0.01
42							10.90	14.35	7.87	6.49	4.68	1.84	3.27	0.77	2.09	0.26	1.20	0.07	0.53	0.01
44							11.42	15.65	8.24	7.08	4.91	2.00	3.43	0.84	2.19	0.28	1.25	0.07	0.55	0.01
46							11.94	16.99	8.61	7.69	5.13	2.18	3.58	0.91	2.29	0.31	1.31	0.08	0.58	0.01
48							12.45	18.38	8.99	8.32	5.35	2.35	3.74	0.98	2.39	0.33	1.37	0.08	0.60	0.01
50							12.97	19.83	9.36	8.97	5.57	2.54	3.89	1.06	2.49	0.36	1.42	0.09	0.63	0.01
55							14.27	23.65	10.30	10.70	6.13	3.03	4.28	1.27	2.74	0.43	1.57	0.11	0.69	0.01
60							15.57	27.79	11.24	12.57	6.69	3.56	4.67	1.49	2.98	0.50	1.71	0.13	0.75	0.02
65									12.17	14.58	7.25	4.13	5.06	1.72	3.23	0.58	1.85	0.15	0.81	0.02
70									13.11	16.73	7.80	4.74	5.45	1.98	3.48	0.66	1.99	0.17	0.88	0.02
75									14.05	19.01	8.36	5.38	5.84	2.25	3.73	0.76	2.13	0.19	0.94	0.03
80									14.98	21.42	8.92	6.06	6.23	2.53	3.98	0.85	2.28	0.22	1.00	0.03
85									15.92	23.96	9.48	6.78	6.62	2.83	4.23	0.95	2.42	0.24	1.06	0.03
90											10.03	7.54	7.01	3.15	4.48	1.06	2.56	0.27	1.13	0.04
95											10.59	8.34	7.40	3.48	4.73	1.17	2.70	0.30	1.19	0.04
100											11.15	9.17	7.79	3.83	4.97	1.29	2.85	0.33	1.25	0.04
110											12.26	10.94	8.57	4.57	5.47	1.53	3.13	0.39	1.38	0.05
120											13.38	12.85	9.34	5.37	5.97	1.80	3.42	0.46	1.50	0.06
130											14.49	14.90	10.12	6.22	6.47	2.09	3.70	0.54	1.63	0.07
140											15.61	17.09	10.90	7.14	6.96	2.40	3.98	0.62	1.75	0.08
150													11.68	8.11	7.46	2.73	4.27	0.70	1.88	0.10
160													12.46	9.14	7.96	3.07	4.55	0.79	2.00	0.11
170													13.24	10.23	8.46	3.44	4.84	0.88	2.13	0.12
180													14.02	11.37	8.95	3.82	5.12	0.98	2.25	0.13
190													14.80	12.57	9.45	4.22	5.41	1.09	2.38	0.15
200													15.57	13.82	9.95	4.64	5.69	1.19	2.50	0.16
220															10.94	5.54	6.26	1.42	2.75	0.19
240															11.94	6.51	6.83	1.67	3.00	0.23
260															12.93	7.55	7.40	1.94	3.25	0.26
280															13.93	8.66	7.97	2.23	3.51	0.30
300															14.92	9.84	8.54	2.53	3.76	0.34
320															15.92	11.09	9.11	2.85	4.01	0.39
340																	9.68	3.19	4.26	0.43
360																	10.25	3.55	4.51	0.48
380																	10.82	3.92	4.76	0.53
400																	11.39	4.31	5.01	0.58
420																	11.95	4.72	5.26	0.64
440																	12.52	5.14	5.51	0.70
460																	13.09	5.59	5.76	0.76
480																	13.66	6.04	6.01	0.82
500																	14.23	6.52	6.26	0.88
Working pressure	850 psi		690 psi		630 psi		520 psi		470 psi		430 psi		400 psi		380 psi		330 psi		280 psi	

Shaded area represents velocities over 5 ft/s. Use with caution.

Irrigation Association Friction Loss Chart 2008

Polyethylene Plastic Pipe (ID controlled)

PE 3408 ASTM D2239 C=140

psi loss per 100 feet of pipe

Nominal size / Avg. ID	1/2" 0.622		3/4" 0.824		1" 1.049		1-1/4" 1.380		1-1/2" 1.610		2" 2.067		2-1/2" 2.469		3" 3.068		4" 4.026	
Flow (gpm)	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss
1	1.05	0.49	0.60	0.12	0.37	0.04	0.21	0.01	0.16	0.00								
2	2.11	1.76	1.20	0.45	0.74	0.14	0.43	0.04	0.31	0.02	0.19	0.01						
3	3.16	3.73	1.80	0.95	1.11	0.29	0.64	0.08	0.47	0.04	0.29	0.01						
4	4.22	6.35	2.40	1.62	1.48	0.50	0.86	0.13	0.63	0.06	0.38	0.02	0.27	0.01				
5	5.27	9.60	3.00	2.44	1.85	0.76	1.07	0.20	0.79	0.09	0.48	0.03	0.33	0.01				
6	6.33	13.46	3.61	3.43	2.22	1.06	1.29	0.28	0.94	0.13	0.57	0.04	0.40	0.02	0.26	0.01		
7	7.38	17.91	4.21	4.56	2.60	1.41	1.50	0.37	1.10	0.18	0.67	0.05	0.47	0.02	0.30	0.01		
8	8.44	22.93	4.81	5.84	2.97	1.80	1.71	0.47	1.26	0.22	0.76	0.07	0.54	0.03	0.35	0.01		
9	9.49	28.52	5.41	7.26	3.34	2.24	1.93	0.59	1.42	0.28	0.86	0.08	0.60	0.03	0.39	0.01		
10	10.55	34.67	6.01	8.82	3.71	2.73	2.14	0.72	1.57	0.34	0.95	0.10	0.67	0.04	0.43	0.01		
12			7.21	12.37	4.45	3.82	2.57	1.01	1.89	0.48	1.15	0.14	0.80	0.06	0.52	0.02		
14			8.41	16.45	5.19	5.08	3.00	1.34	2.20	0.63	1.34	0.19	0.94	0.08	0.61	0.03		
16			9.61	21.07	5.93	6.51	3.43	1.71	2.52	0.81	1.53	0.24	1.07	0.10	0.69	0.04	0.40	0.01
18			10.82	26.21	6.67	8.10	3.86	2.13	2.83	1.01	1.72	0.30	1.20	0.13	0.78	0.04	0.45	0.01
20			12.02	31.85	7.42	9.84	4.28	2.59	3.15	1.22	1.91	0.36	1.34	0.15	0.87	0.05	0.50	0.01
22					8.16	11.74	4.71	3.09	3.46	1.46	2.10	0.43	1.47	0.18	0.95	0.06	0.55	0.02
24					8.90	13.79	5.14	3.63	3.78	1.72	2.29	0.51	1.61	0.21	1.04	0.07	0.60	0.02
26					9.64	16.00	5.57	4.21	4.09	1.99	2.48	0.59	1.74	0.25	1.13	0.09	0.65	0.02
28					10.38	18.35	6.00	4.83	4.41	2.28	2.67	0.68	1.87	0.28	1.21	0.10	0.70	0.03
30					11.12	20.85	6.43	5.49	4.72	2.59	2.86	0.77	2.01	0.32	1.30	0.11	0.76	0.03
32					11.86	23.50	6.86	6.19	5.04	2.92	3.06	0.87	2.14	0.36	1.39	0.13	0.81	0.03
34					12.61	26.29	7.28	6.92	5.35	3.27	3.25	0.97	2.28	0.41	1.47	0.14	0.86	0.04
36							7.71	7.69	5.67	3.63	3.44	1.08	2.41	0.45	1.56	0.16	0.91	0.04
38							8.14	8.50	5.98	4.02	3.63	1.19	2.54	0.50	1.65	0.17	0.96	0.05
40							8.57	9.35	6.30	4.42	3.82	1.31	2.68	0.55	1.73	0.19	1.01	0.05
42							9.00	10.24	6.61	4.83	4.01	1.43	2.81	0.60	1.82	0.21	1.06	0.06
44							9.43	11.16	6.93	5.27	4.20	1.56	2.94	0.66	1.91	0.23	1.11	0.06
46							9.86	12.12	7.24	5.72	4.39	1.70	3.08	0.71	1.99	0.25	1.16	0.07
48							10.28	13.11	7.56	6.19	4.58	1.84	3.21	0.77	2.08	0.27	1.21	0.07
50							10.71	14.14	7.87	6.68	4.77	1.98	3.35	0.83	2.17	0.29	1.26	0.08
55							11.78	16.87	8.66	7.97	5.25	2.36	3.68	0.99	2.38	0.35	1.38	0.09
60							12.85	19.82	9.44	9.36	5.73	2.77	4.02	1.17	2.60	0.41	1.51	0.11
65									10.23	10.86	6.21	3.22	4.35	1.36	2.82	0.47	1.64	0.13
70									11.02	12.45	6.68	3.69	4.69	1.55	3.03	0.54	1.76	0.14
75									11.81	14.15	7.16	4.19	5.02	1.77	3.25	0.61	1.89	0.16
80									12.59	15.95	7.64	4.73	5.35	1.99	3.47	0.69	2.01	0.18
85									13.38	17.84	8.12	5.29	5.69	2.23	3.68	0.77	2.14	0.21
90											8.59	5.88	6.02	2.48	3.90	0.86	2.27	0.23
95											9.07	6.50	6.36	2.74	4.12	0.95	2.39	0.25
100											9.55	7.15	6.69	3.01	4.33	1.05	2.52	0.28
110											10.50	8.53	7.36	3.59	4.77	1.25	2.77	0.33
120											11.46	10.02	8.03	4.22	5.20	1.47	3.02	0.39
130											12.41	11.62	8.70	4.89	5.63	1.70	3.27	0.45
140											13.37	13.33	9.37	5.61	6.07	1.95	3.52	0.52
150													10.04	6.38	6.50	2.22	3.78	0.59
160													10.71	7.19	6.94	2.50	4.03	0.67
170													11.38	8.04	7.37	2.79	4.28	0.74
180													12.05	8.94	7.80	3.11	4.53	0.83
190													12.72	9.88	8.24	3.43	4.78	0.92
200													13.39	10.87	8.67	3.78	5.03	1.01
220															9.54	4.50	5.54	1.20
240															10.40	5.29	6.04	1.41
260															11.27	6.14	6.54	1.64
280															12.14	7.04	7.05	1.88
300															13.00	8.00	7.55	2.13
320															13.87	9.02	8.05	2.40
340																	8.56	2.69
360																	9.06	2.99
380																	9.57	3.30
400																	10.07	3.63
420																	10.57	3.98
440																	11.08	4.33
460																	11.58	4.71
480																	12.08	5.09
500																	12.59	5.49

Shaded area represents velocities over 5 ft/s. Use with caution.

Irrigation Association Friction Loss Chart 2008

Type "K" Copper Tubing

ASTM B88 C=140

psi loss per 100 feet of pipe

Nominal size	1/2"		5/8"		3/4"		1"		1-1/4"		1-1/2"		2"		2-1/2"		3"	
Pipe ID	0.527		0.652		0.745		0.995		1.245		1.481		1.959		2.435		2.907	
Pipe OD	0.625		0.750		0.875		1.125		1.375		1.625		2.125		2.625		3.125	
Avg. wall	0.049		0.049		0.065		0.065		0.065		0.072		0.083		0.095		0.109	
Flow (gpm)	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss	Velocity (ft/s)	psi loss
1	1.47	1.09	0.96	0.39	0.74	0.20	0.41	0.05	0.26	0.02								
2	2.94	3.94	1.92	1.40	1.47	0.73	0.82	0.18	0.53	0.06								
3	4.41	8.35	2.88	2.97	2.21	1.55	1.24	0.38	0.79	0.13								
4	5.88	14.23	3.84	5.05	2.94	2.64	1.65	0.65	1.05	0.22								
5	7.35	21.51	4.80	7.64	3.68	3.99	2.06	0.98	1.32	0.33								
6	8.81	30.15	5.76	10.70	4.41	5.59	2.47	1.37	1.58	0.46	1.12	0.20						
7	10.28	40.12	6.72	14.24	5.15	7.44	2.88	1.82	1.84	0.61	1.30	0.26						
8	11.75	51.37	7.68	18.24	5.88	9.53	3.30	2.33	2.11	0.78	1.49	0.34						
9	13.22	63.90	8.64	22.68	6.62	11.85	3.71	2.90	2.37	0.97	1.67	0.42						
10	14.69	77.66	9.60	27.57	7.35	14.41	4.12	3.52	2.63	1.18	1.86	0.51						
12			11.52	38.64	8.82	20.20	4.95	4.94	3.16	1.66	2.23	0.71	1.28	0.18				
14			13.44	51.41	10.29	26.87	5.77	6.57	3.69	2.21	2.60	0.95	1.49	0.24				
16			15.36	65.83	11.76	34.41	6.59	8.42	4.21	2.83	2.98	1.22	1.70	0.31				
18			17.28	81.88	13.23	42.80	7.42	10.47	4.74	3.52	3.35	1.51	1.91	0.39				
20					14.70	52.02	8.24	12.72	5.26	4.28	3.72	1.84	2.13	0.47				
22					16.17	62.06	9.07	15.18	5.79	5.10	4.09	2.19	2.34	0.56	1.51	0.19	1.06	0.08
24					17.64	72.91	9.89	17.84	6.32	5.99	4.46	2.58	2.55	0.66	1.65	0.23	1.16	0.10
26							10.71	20.69	6.84	6.95	4.84	2.99	2.76	0.77	1.79	0.27	1.26	0.11
28							11.54	23.73	7.37	7.97	5.21	3.43	2.98	0.88	1.93	0.30	1.35	0.13
30							12.36	26.96	7.90	9.06	5.58	3.89	3.19	1.00	2.06	0.35	1.45	0.15
32							13.19	30.39	8.42	10.21	5.95	4.39	3.40	1.12	2.20	0.39	1.54	0.16
34							14.01	34.00	8.95	11.42	6.32	4.91	3.61	1.26	2.34	0.44	1.64	0.18
36							14.84	37.79	9.48	12.70	6.70	5.46	3.83	1.40	2.48	0.49	1.74	0.20
38							15.66	41.77	10.00	14.04	7.07	6.03	4.04	1.55	2.61	0.54	1.83	0.23
40							16.48	45.94	10.53	15.43	7.44	6.63	4.25	1.70	2.75	0.59	1.93	0.25
42							17.31	50.28	11.06	16.89	7.81	7.26	4.47	1.86	2.89	0.65	2.03	0.27
44									11.58	18.41	8.18	7.91	4.68	2.03	3.03	0.70	2.12	0.30
46									12.11	19.99	8.56	8.59	4.89	2.20	3.17	0.76	2.22	0.32
48									12.63	21.63	8.93	9.30	5.10	2.38	3.30	0.83	2.32	0.35
50									13.16	23.33	9.30	10.03	5.32	2.57	3.44	0.89	2.41	0.38
55									14.48	27.84	10.23	11.96	5.85	3.07	3.78	1.06	2.66	0.45
60									15.79	32.70	11.16	14.05	6.38	3.60	4.13	1.25	2.90	0.53
65									17.11	37.93	12.09	16.30	6.91	4.18	4.47	1.45	3.14	0.61
70									18.43	43.51	13.02	18.70	7.44	4.79	4.82	1.66	3.38	0.70
75											13.95	21.24	7.97	5.45	5.16	1.89	3.62	0.80
80											14.88	23.94	8.51	6.14	5.50	2.13	3.86	0.90
85											15.81	26.79	9.04	6.87	5.85	2.38	4.10	1.01
90											16.74	29.78	9.57	7.63	6.19	2.65	4.35	1.12
95											17.67	32.91	10.10	8.44	6.54	2.93	4.59	1.24
100											18.60	36.19	10.63	9.28	6.88	3.22	4.83	1.36
110													11.69	11.07	7.57	3.84	5.31	1.62
120													12.76	13.01	8.26	4.51	5.79	1.91
130													13.82	15.08	8.95	5.23	6.28	2.21
140													14.88	17.30	9.63	6.00	6.76	2.54
150													15.95	19.66	10.32	6.82	7.24	2.88
160													17.01	22.16	11.01	7.69	7.72	3.25
170													18.07	24.79	11.70	8.60	8.21	3.63
180															12.39	9.56	8.69	4.04
190															13.07	10.57	9.17	4.46
200															13.76	11.62	9.66	4.91
220															15.14	13.87	10.62	5.86
240															16.51	16.29	11.59	6.88
260															17.89	18.90	12.55	7.98
280															19.27	21.68	13.52	9.15
300																	14.48	10.40
320																	15.45	11.72
340																	16.42	13.14
360																	17.38	14.58
380																	18.35	16.11
400																		
420																		
440																		
460																		
480																		
500																		

Shaded area represents velocities over 7 ft/s.
Use with caution where water hammer is a concern.

Irrigation Association Friction Loss Chart 2008

Schedule 40 Steel

ASTM B53 C=100

psi loss per 100 feet of pipe

Nominal size	1/2"		3/4"		1"		1-1/4"		1-1/2"		2"		2-1/2"		3"		4"	
Pipe ID	0.622		0.824		1.049		1.38		1.610		2.067		2.469		3.068		4.026	
Pipe OD	0.842		1.050		1.315		1.660		1.900		2.375		2.875		3.500		4.500	
Avg. wall	0.110		0.113		0.133		0.140		0.145		0.154		0.203		0.216		0.237	
Flow {gpm}	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss
1	1.05	0.91	0.60	0.23	0.37	0.07	0.21	0.02	0.16	0.01								
2	2.11	3.28	1.20	0.84	0.74	0.26	0.43	0.07	0.31	0.03								
3	3.16	6.95	1.80	1.77	1.11	0.55	0.64	0.14	0.47	0.07								
4	4.22	11.85	2.40	3.02	1.48	0.93	0.86	0.25	0.63	0.12								
5	5.27	17.91	3.00	4.56	1.85	1.41	1.07	0.37	0.79	0.18								
6	6.33	25.10	3.61	6.39	2.22	1.97	1.29	0.52	0.94	0.25	0.57	0.07						
7	7.38	33.40	4.21	8.50	2.60	2.63	1.50	0.69	1.10	0.33	0.67	0.10						
8	8.44	42.77	4.81	10.88	2.97	3.36	1.71	0.89	1.26	0.42	0.76	0.12						
9	9.49	53.19	5.41	13.54	3.34	4.18	1.93	1.10	1.42	0.52	0.86	0.15						
10	10.55	64.65	6.01	16.45	3.71	5.08	2.14	1.34	1.57	0.63	0.95	0.19						
12	12.65	90.62	7.21	23.06	4.45	7.12	2.57	1.88	1.89	0.89	1.15	0.26	0.80	0.11				
14			8.41	30.68	5.19	9.48	3.00	2.50	2.20	1.18	1.34	0.35	0.94	0.15				
16			9.61	39.29	5.93	12.14	3.43	3.20	2.52	1.51	1.53	0.45	1.07	0.19				
18			10.82	48.87	6.67	15.10	3.86	3.97	2.83	1.88	1.72	0.56	1.20	0.23				
20			12.02	59.40	7.42	18.35	4.28	4.83	3.15	2.28	1.91	0.68	1.34	0.28				
22			13.22	70.87	8.16	21.89	4.71	5.76	3.46	2.72	2.10	0.81	1.47	0.34	0.95	0.12	0.55	0.03
24					8.90	25.72	5.14	6.77	3.78	3.20	2.29	0.95	1.61	0.40	1.04	0.14	0.60	0.04
26					9.64	29.83	5.57	7.85	4.09	3.71	2.48	1.10	1.74	0.46	1.13	0.16	0.65	0.04
28					10.38	34.22	6.00	9.01	4.41	4.25	2.67	1.26	1.87	0.53	1.21	0.18	0.70	0.05
30					11.12	38.88	6.43	10.24	4.72	4.83	2.86	1.43	2.01	0.60	1.30	0.21	0.76	0.06
32					11.86	43.81	6.86	11.54	5.04	5.45	3.06	1.62	2.14	0.68	1.39	0.24	0.81	0.06
34					12.61	49.02	7.28	12.91	5.35	6.10	3.25	1.81	2.28	0.76	1.47	0.26	0.86	0.07
36					13.35	54.49	7.71	14.35	5.67	6.78	3.44	2.01	2.41	0.85	1.56	0.29	0.91	0.08
38							8.14	15.86	5.98	7.49	3.63	2.22	2.54	0.94	1.65	0.33	0.96	0.09
40							8.57	17.44	6.30	8.24	3.82	2.44	2.68	1.03	1.73	0.36	1.01	0.10
42							9.00	19.09	6.61	9.02	4.01	2.67	2.81	1.13	1.82	0.39	1.06	0.10
44							9.43	20.81	6.93	9.83	4.20	2.91	2.94	1.23	1.91	0.43	1.11	0.11
46							9.86	22.59	7.24	10.67	4.39	3.16	3.08	1.33	1.99	0.46	1.16	0.12
48							10.28	24.44	7.56	11.55	4.58	3.42	3.21	1.44	2.08	0.50	1.21	0.13
50							10.71	26.36	7.87	12.45	4.77	3.69	3.35	1.55	2.17	0.54	1.26	0.14
55							11.78	31.45	8.66	14.86	5.25	4.40	3.68	1.85	2.38	0.64	1.38	0.17
60							12.85	36.95	9.44	17.45	5.73	5.17	4.02	2.18	2.60	0.76	1.51	0.20
65							13.93	42.86	10.23	20.24	6.21	6.00	4.35	2.53	2.82	0.88	1.64	0.23
70									11.02	23.22	6.68	6.88	4.69	2.90	3.03	1.01	1.76	0.27
75									11.81	26.39	7.16	7.82	5.02	3.29	3.25	1.14	1.89	0.31
80									12.59	29.74	7.64	8.82	5.35	3.71	3.47	1.29	2.01	0.34
85									13.38	33.27	8.12	9.86	5.69	4.15	3.68	1.44	2.14	0.38
90											8.59	10.96	6.02	4.62	3.90	1.60	2.27	0.43
95											9.07	12.12	6.36	5.10	4.12	1.77	2.39	0.47
100											9.55	13.33	6.69	5.61	4.33	1.95	2.52	0.52
110											10.50	15.90	7.36	6.70	4.77	2.33	2.77	0.62
120											11.46	18.68	8.03	7.87	5.20	2.73	3.02	0.73
130											12.41	21.66	8.70	9.12	5.63	3.17	3.27	0.85
140											13.37	24.85	9.37	10.47	6.07	3.64	3.52	0.97
150													10.04	11.89	6.50	4.13	3.78	1.10
160													10.71	13.40	6.94	4.66	4.03	1.24
170													11.38	15.00	7.37	5.21	4.28	1.39
180													12.05	16.67	7.80	5.79	4.53	1.54
190													12.72	18.43	8.24	6.40	4.78	1.71
200													13.39	20.26	8.67	7.04	5.03	1.88
220															9.54	8.40	5.54	2.24
240															10.40	9.87	6.04	2.63
260															11.27	11.45	6.54	3.05
280															12.14	13.13	7.05	3.50
300															13.00	14.92	7.55	3.98
320															13.87	16.81	8.05	4.48
340																	8.56	5.01
360																	9.06	5.57
380																	9.57	6.16
400																	10.07	6.77
420																	10.57	7.42
440																	11.08	8.08
460																	11.58	8.78
480																	12.08	9.50
500																	12.59	10.24

Shaded area represents velocities over 7 ft/s.
Use with caution where water hammer is a concern.

Water Meter Pressure Loss Chart

Typical Pressure Losses (psi)

Flow (gpm)	Nominal size 5/8"	3/4"	1"	1-1/2"	2"	3"	4"
1	0.2	0.1					
2	0.3	0.2					
3	0.4	0.3					
4	0.6	0.5	0.1				
5	0.9	0.6	0.2				
6	1.3	0.7	0.3				
7	1.8	0.8	0.4				
8	2.3	1.0	0.5				
9	3.0	1.3	0.6				
10	3.7	1.6	0.7				
11	4.4	1.9	0.8				
12	5.1	2.2	0.9				
13	6.1	2.6	1.0				
14	7.2	3.1	1.1				
15	8.3	3.6	1.2				
16	9.4	4.1	1.4	0.4			
17	10.7	4.6	1.6	0.5			
18	12.0	5.2	1.8	0.6			
19	13.4	5.8	2.0	0.7			
20	15.0	6.5	2.2	0.8			
22		7.9	2.8	1.0			
24		9.5	3.4	1.2			
26		11.2	4.0	1.4			
28		13.0	4.6	1.6			
30		15.0	5.3	1.8	0.7		
32			6.0	2.1	0.8		
34			6.9	2.4	0.9		
36			7.8	2.7	1.0		
38			8.7	3.0	1.2		
40			9.6	3.3	1.3		
42			10.6	3.6	1.4		
44			11.7	3.9	1.5		
46			12.8	4.2	1.6		
48			13.9	4.5	1.7		
50			15.0	4.9	1.9		
52				5.3	2.1		
54				5.7	2.2		
56				6.2	2.3		
58				6.7	2.5		
60				7.2	2.7	1.0	
65				8.3	3.2	1.1	
70				9.8	3.7	1.3	
75				11.3	4.3	1.5	
80				12.8	4.9	1.6	0.7
90				16.1	6.2	2.0	0.8
100				20.0	7.8	2.5	0.9
110					9.5	2.9	1.0
120					11.3	3.4	1.2
130					13.0	3.9	1.4
140					15.1	4.5	1.6
150					17.3	5.1	1.8
160					20.0	5.8	2.1
170						6.5	2.4
180						7.2	2.7
190						8.0	3.0
200						9.0	3.2
220						11.0	3.9
240						13.0	4.7
260						15.0	5.5
280						17.3	6.3
300						20.0	7.2
350							10.0
400							13.0
450							16.2
500							20.0
75% of max meter capacity	15 gpm	22.5 gpm	37.5 gpm	75 gpm	120 gpm	225 gpm	375 gpm

Shaded areas exceed 75% of maximum safe meter capacity.

Typical Pressure Loss in Backflow Prevention Devices

{psi}

	Pressure vacuum breaker					Double check assembly					Reduced pressure principle assembly				
gpm	3/4"	1"	1-1/4"	1-1/2"	2"	3/4"	1"	1-1/4"	1-1/2"	2"	3/4"	1"	1-1/4"	1-1/2"	2"
5	3.5					5.5					10.5				
10	4.0					6.0					11.2				
15	4.6	2.9				6.9					11.9				
20	5.5	4.2				8.0	5.5				12.7	12.0			
25	6.5	4.5				8.9	5.7				13.3	12.1			
30	7.5	5.0	4.5			9.5	6.0				14.0	12.2	13.8		
35		5.5	4.8			10.5	6.5				15.1	12.4	13.9		
40		6.0	5.1	3.6		11.5	7.1	6.7			16.9	12.8	14.1		
45		6.6	5.4	3.7			8.0	7.0				13.1	14.3		
50		7.5	5.6	3.8			8.9	7.5				13.7	14.5		
55		8.0	5.9	3.9			9.5	7.7				14.3	14.8		
60		8.5	6.2	4.0	4.5		10.0	8.0	6.8			15.0	15.0	13.7	
70			6.8	4.2	5.0		12.3	8.5	7.0			16.5	15.5	14.0	
80			7.5	4.6	5.1			9.1	7.2				16.0	14.2	13.1
90				4.8	5.3			10.0	7.5				16.8	14.8	13.3
100				5.0	5.6			10.9	7.9	6.5			17.5	15.0	13.5
110				5.5	5.8				8.1	6.8				15.2	13.7
120				5.9	5.9				8.5	7.0				15.8	13.9
130				6.9	6.0				9.0	7.2				16.1	14.1
140					6.1				9.5	7.8				16.9	14.4
150					6.2				10.5	8.1					14.9
160					6.5					8.5					15.1
170					6.8					9.0					15.8
180					7.0					9.4					16.5
190					7.2					9.9					17.1
200					7.5					10.2					18.0

Pressure Loss Through Globe Valves

{psi}

Flow {gpm}	Valve size 1/2"	3/4"	1"	1-1/4"	1-1/2"	2"	2-1/2"	3"	4"
2	0.6								
4	2.2	0.7							
6	4.7	1.5	0.6						
8	7.9	2.5	1.0						
10	12.2	3.8	1.5						
12	17.2	5.3	2.1	0.7					
14	22.8	7.1	2.8	0.9					
16		9.0	3.6	1.2	0.7				
18		11.2	4.4	1.5	0.9				
20		13.7	5.4	1.9	1.0				
22		16.2	6.4	2.2	1.2				
24		19.0	7.5	2.6	1.4				
26		22.1	8.7	3.0	1.7				
28			10.0	3.4	1.9	0.7			
30			11.3	3.9	2.2	0.8			
32			12.8	4.4	2.5	0.9			
34			14.3	4.9	2.5	1.0			
36			16.0	5.5	3.0	1.2			
38			17.7	6.1	3.4	1.3			
40			19.5	6.7	3.7	1.4			
42			21.3	7.3	4.1	1.5			
44				8.0	4.4	1.7			
46				8.7	4.8	1.8	0.9		
48				9.4	5.2	20	1.0		
50				10.1	5.6	2.1	1.1		
55				12.2	6.6	2.5	1.3		
60				14.2	7.8	3.0	1.5	0.7	
65				16.6	9.1	3.5	1.7	0.8	
70				19.0	10.4	4.0	2.0	0.9	
75					11.7	4.5	2.2	1.0	
80					13.3	5.1	2.5	1.1	
90					16.6	6.3	3.2	1.4	
100					20.2	7.7	3.8	2.0	0.6
120						10.7	5.4	2.7	0.8
140						14.3	7.2	3.5	1.1
160						18.3	9.2	4.4	1.4
180						22.7	11.4	5.5	1.7
200							13.9	6.6	2.1
250							20.9	9.7	3.2
300								14.7	4.5
350								16.9	6.0
400								21.6	7.6
450									9.4
500									11.4

Pressure Loss Through Angle Valves

{psi}

Flow {gpm}	Valve size 1/2"	3/4"	1"	1-1/4"	1-1/2"	2"	2-1/2"	3"	4"
2	0.3								
4	1.1	0.4							
6	2.3	0.7	0.3						
8	4.0	1.2	0.5						
10	5.8	1.9	0.7						
12	8.1	2.7	1.0	0.4					
14	10.8	3.5	1.4	0.5					
16		4.5	1.8	0.6					
18		5.6	2.2	0.8	0.4				
20		6.8	2.7	0.9	0.5				
22		8.5	3.2	1.1	0.6				
24		9.9	3.8	1.3	0.7				
26		11.5	4.4	1.5	0.8				
28			5.0	1.7	1.0				
30			5.7	2.0	1.1	0.4			
32			6.4	2.2	1.2	0.5			
34			7.2	2.5	1.4	0.5			
36			8.0	2.8	1.5	0.6			
38			8.9	3.1	1.7	0.6			
40			9.7	3.3	1.9	0.7			
42			10.7	3.7	2.0	0.8			
44				4.0	2.2	0.8			
46				4.3	2.4	0.9			
48				4.7	2.6	1.0			
50				5.1	2.8	1.1	0.5		
55				6.0	3.4	1.3	0.6		
60				7.1	3.9	1.5	0.8		
65				8.2	4.5	1.7	0.9		
70				9.4	5.2	2.0	1.0	0.4	
75					5.9	2.2	1.1	0.5	
80					6.7	2.5	1.3	0.6	
90					8.3	3.2	1.6	0.7	
100					10.1	3.8	2.0	0.8	
120						5.4	2.7	1.2	0.4
140						7.1	3.6	1.6	0.5
160						9.1	4.7	2.0	0.7
180						11.4	5.8	2.5	0.9
200						13.8	7.0	3.0	1.1
250							10.6	4.5	1.6
300							14.9	6.4	2.2
350								8.4	3.0
400								10.8	3.8
450									4.7
500									5.8

Standard Pipe Dimensions

(in.)

Nominal pipe size	Outside diameter	Rigid plastic pipe – SDR 26 Avg. inside diameter	SDR 26 Min. wall thickness	SDR 21 Avg. inside diameter	SDR 21 Min. wall thickness	SDR 13.5 Avg. inside diameter	SDR 13.5 Min. wall thickness
1/2"	0.840					0.696	0.062
3/4"	1.050			0.910	0.060	0.874	0.078
1"	1.315	1.175	0.060	1.169	0.063	1.101	0.097
1-1/4"	1.660	1.512	0.064	1.482	0.079	1.394	0.123
1-1/2"	1.900	1.734	0.073	1.700	0.090	1.598	0.141
2"	2.375	2.173	0.091	2.129	0.113	1.983	0.176
2-1/2"	2.875	2.635	0.110	2.581	0.137	2.423	0.213
3"	3.500	3.210	0.135	3.146	0.167	2.948	0.259
4"	4.500	4.134	0.173	4.046	0.214	3.794	0.333

Nominal pipe size	Outside diameter	Plastic pipe – Schedule 40 Avg. inside diameter	Schedule 40 Min. wall thickness	Schedule 80 Avg. inside diameter	Schedule 80 Min. wall thickness
1/2"	0.840	0.602	0.109	0.526	0.147
3/4"	1.050	0.804	0.113	0.722	0.154
1"	1.315	1.029	0.133	0.935	0.179
1-1/4"	1.660	1.360	0.140	1.254	0.191
1-1/2"	1.900	1.590	0.145	1.476	0.200
2"	2.375	2.047	0.154	1.913	0.218
2-1/2"	2.875	2.445	0.203	2.289	0.276
3"	3.500	3.042	0.216	2.864	0.300
4"	4.500	3.998	0.237	3.786	0.337

Nominal pipe size	Outside diameter	Plastic DWV – ABS Inside diameter	Min. wall thickness
1-1/2"	1.660	1.380	0.140
2"	1.900	1.610	0.145
2-1/2"	2.375	2.067	0.154
3"	3.500	3.068	0.216
4"	4.500	4.026	0.237

Nominal pipe size	Inside diameter	Flexible polyethylene pipe – SDR 15 Outside diameter	SDR 15 Wall thickness	SDR 11.5 Outside diameter	SDR 11.5 Wall thickness	SDR 9 Outside diameter	SDR 9 Wall thickness	SDR 7 Outside diameter	SDR 7 Wall thickness
1/2"	0.622	0.742	0.060	0.742	0.060	0.760	0.069	0.800	0.089
3/4"	0.824	0.944	0.060	0.968	0.072	1.008	0.092	1.060	0.118
1"	1.049	1.189	0.070	1.231	0.091	1.283	0.117	1.349	0.150
1-1/4"	1.380	1.564	0.092	1.620	0.120	4.686	0.153	1.774	0.197
1-1/2"	1.610	1.824	0.107	1.890	0.140	7.968	0.179	2.070	0.230
2"	2.067	2.343	0.138	2.427	0.180	2.527	0.230	2.657	0.295
2-1/2"	2.469	2.799	0.165	2.899	0.215				

Nominal pipe size	Outside diameter	Copper water tube – Drain, waste & vent Inside diameter	Drain, waste & vent Avg. wall thickness	Type "M" Inside diameter	Type "M" Avg. wall thickness	Type "L" Inside diameter	Type "L" Avg. wall thickness	Type "K" Inside diameter	Type "K" Avg. wall thickness
1/2"	0.625			0.569	0.028	0.545	0.040	0.527	0.049
3/4"	0.875			0.811	0.032	0.785	0.045	0.745	0.065
1"	1.125			1.055	0.035	1.025	0.050	0.995	0.065
1-1/4"	1.375	1.295	0.040	1.291	0.042	1.265	0.055	1.245	0.065
1-1/2"	1.625	1.541	0.042	1.527	0.049	1.505	0.060	1.481	0.072
2"	2.125	2.041	0.042	2.009	0.058	1.985	0.070	1.959	0.083
2-1/2"	2.625			2.495	0.065	2.465	0.080	2.435	0.095
3"	3.125	3.035	0.045	2.981	0.072	2.945	0.090	2.907	0.109
4"	4.125	4.009	0.058	3.953	0.095	3.905	0.110	3.857	0.134

System Pressure Loss Worksheet

System Pressure Loss Worksheet

Component	Type/Size	Length	Loss or Loss/100 ft	Pressure Loss/Gain
Needed by Sprinkler				
Losses				
Lateral Pipe				
Mainline Pipe				
Lateral and Mainline Fittings				
Zone Valve				
Master Valve				
Backflow Prevention Device				
Pipe to Backflow				
Main Valve				
Pipe to POC				
Water Meter				
Service Line to Meter				
Misc.				
Misc.				
Misc.				
Elevation (+ or –)				
Total Pressure Required				