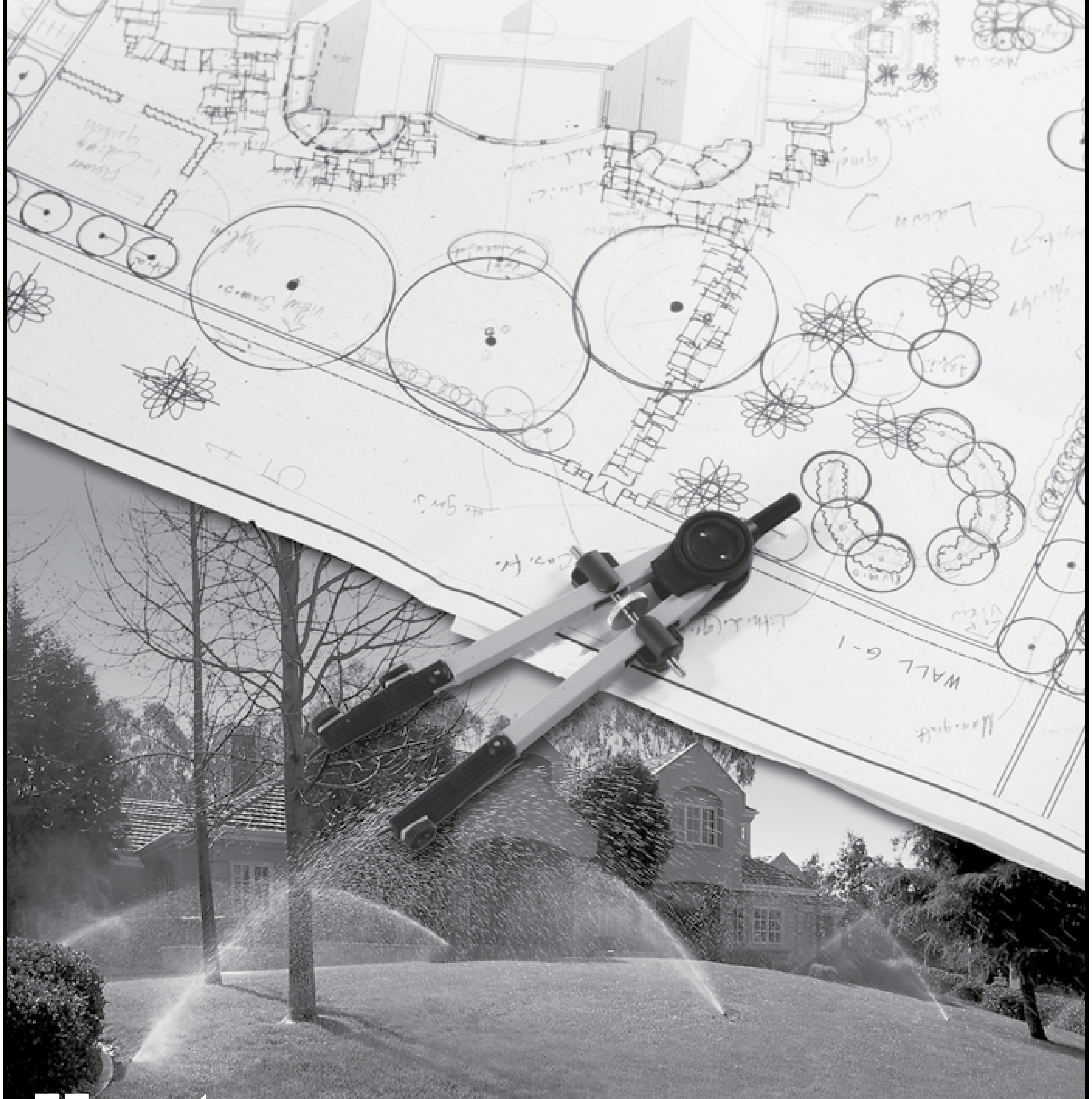
Precipitation Rates and Sprinkler Irrigation

Student's Manual *(Metric)*



Hunter® Irrigation Design Education Module

Table of Contents

Introduction

Today's irrigation designer or system manager faces a multitude of concerns including:

- increased costs for water
- higher bills for pumping
- excessive runoff
- too much or too little water applied
- wet spots that do not allow use of a turf or landscape
- dry spots that are unsightly or cause lost plant material
- increased pests and diseases

Each of these can be related to precipitation rates; thus, understanding precipitation rates can help you avoid these common problems, leading to improved landscapes and reduced costs through better irrigation design and management.

Important Facts to Learn

The purpose of this booklet is to provide an understanding of sprinkler precipitation rates and the importance of matching precipitation rates. After you have read through this material, you should be able to:

1. Define *Precipitation Rate*.[1]
2. Give two reasons why precipitation rates are important in landscape irrigation.
3. Calculate precipitation rates using both standard formulas and the Hunter Precipitation Rate Estimator.
4. Select matched precipitation-rate heads and nozzle combinations from a manufacturer's specifications.

What Is "Precipitation Rate?"

If someone said they were caught in a rainstorm that dropped one inch of water in an hour you would have some idea of how "hard" or "heavily" the rain came down. A rainstorm that covers an area with one millimeter of water in one hour has a "precipitation rate" of one millimeter per hour (1 mm/hr). Similarly, if a sprinkler system applies enough water to cover the irrigated area with one millimeter of water in one hour, the sprinkler system also has a precipitation rate of 1 mm/hr. Thus, the precipitation rate is the speed at which a sprinkler or an irrigation system applies water.

[1] The term "application rate" can be used interchangeably with "precipitation rate."

Are All Precipitation Rates the Same?

Landscape irrigation systems and individual sprinklers themselves have widely varying precipitation rates. The rates typically vary from:

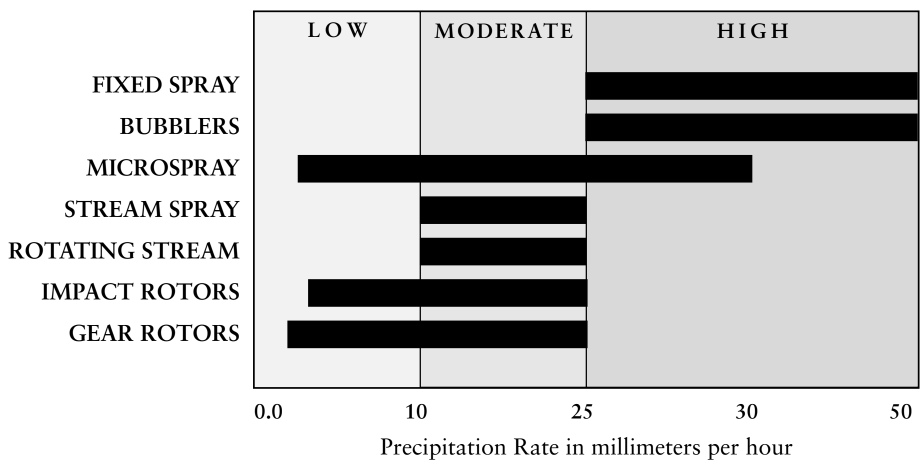
- Low – 10 mm/hr and below
- Medium – 10 to 25 mm/hr
- High – 25 mm/hr and above

These precipitation rates reflect the typical soil infiltration2 rates. Use of sprinklers with high precipitation rates on soils with low infiltration rates would result in excessive runoff.

Sprinkler Type and Expected Precipitation Rate

While the correlation between sprinkler type and precipitation rate is not absolute, the following chart provides a general indication of the precipitation rates you can expect with different types of sprinkler heads.

TYPICAL PRECIPITATION RATE RANGES



High Precipitation Rates – More than 25 mm/hr

Sprinklers with these precipitation rates would be best suited for use on level, coarse-textured soils with high infiltration rates and little hazard of erosion. If used in other conditions they must be operated in short cycles to avoid excessive runoff and soil erosion.

Moderate Precipitation Rates – Between 10 and 25 mm/hr

Sprinklers with these precipitation rates should be used under conditions similar to those described for high precipitation-rate sprinklers. However, these could be operated for somewhat longer cycles than the high precipitation-rate heads.

[2] The term "intake rate" can be used interchangeably with "infiltration rate."

Low-Precipitation Rates – 10 mm/hr or Less

Low precipitation-rate sprinklers have the advantage in that they can be used with a wider variety of slope and soil textures without excessive runoff or soil erosion.

"Sprinkler" Precipitation Rates Versus "System" Precipitation Rates

Depending on the construction of the irrigation system, the precipitation rate quoted may be either a "sprinkler" or a "system" rate.

Sprinkler Precipitation Rates

When the precipitation rate for a "sprinkler" is given, it refers to the rate for a system in which only one specific type of head is used. The precipitation rate for a single sprinkler is calculated using the **Sprinkler Spacing Method**. This method calculates the precipitation rate for those sprinkler heads with the same spacing, rate of flow [in liters per minute (l/min); cubic meters per hour (m^3/hr)] and arc of spray.

System Precipitation Rates

The precipitation rate for a "system" is the average precipitation rate of all sprinklers in an area regardless of the arc, spacing, or flow rate for each head. The system precipitation rate is calculated using the **Total Area Method**. The area for which the calculation is made usually corresponds to all the heads on one irrigation control valve. While individual heads in an area may have different precipitation rates, this method gives you an *average* over the entire area.

The Total Area Method is most useful and accurate when all the heads in the area have similar precipitation rates. Where the precipitation rates of the sprinkler heads vary considerably, the average precipitation rate can be misleading. Where there are differences in precipitation rates, the irrigation system may have applied enough water to the "average" area, but there very likely will be dry spots and wet spots as well.

> **Note:** It is important to remember that precipitation rates and system uniformity are two completely separate issues. Calculated precipitation rates do not reflect how uniformly the water is being applied. System uniformity is an important calculation and should always be taken into account when scheduling irrigation systems or determining minimum water supply requirements. (System uniformity will be covered in detail in another Hunter Education Module.)

Use of Precipitation Rates in Landscape Irrigation

Precipitation rate is critical to selection of sprinkler heads for a system and scheduling sprinkler run times.

Sprinkler Head Selection

When selecting sprinkler heads, it is necessary to limit their precipitation rate to the infiltration rate of the soil. The infiltration rate is affected by the soil texture, soil structure, plant material, and the slope. The following chart gives a relationship between these factors and the infiltration rate of the soil. Failure to limit precipitation rates to the soil infiltration rate can result in excessive runoff and erosion.

SOIL TEXTURE	Maximum Precipitation Rates (millimeters per hour):							
	0 to 5% slope		5 to 8% slope		8 to 12% slope		12% + slope	
	Cover	Bare	Cover	Bare	Cover	Bare	Cover	Bare
Coarse sandy Soils	51	51	51	38	38	25	25	13
Coarse sandy Soils over compact subsoils	44	38	32	25	25	19	19	10
Uniform light sandy loams	44	25	32	20	25	15	19	10
Light sandy loams over compact subsoils	32	19	25	13	19	10	13	8
Uniform silt loams	25	13	20	10	15	8	10	5
Silt loams over compact subsoil	15	8	13	6	10	4	8	3
Heavy clay or clay loam	5	4	4	3	3	2	3	2

The maximum precipitation-rate values listed are as suggested by the United States Department of Agriculture. The values are average and may vary with respect to actual soil conditions and condition of the ground cover.

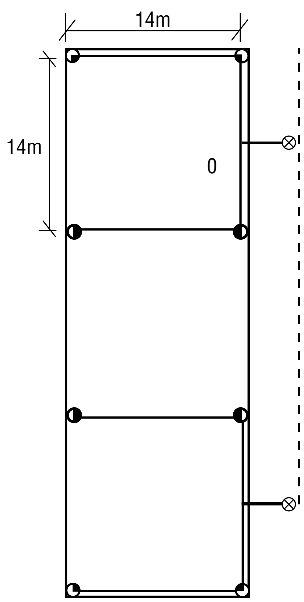
Scheduling Sprinkler Run Time

Scheduling sprinkler run times without knowing the precipitation rate is like trying to estimate your arrival time without knowing how fast you are traveling. The precipitation rate represents the speed at which an amount of water is applied. Knowing this is important because it helps us estimate how long it will take to apply the water needed by the plants in the landscape. The precipitation rate is also required for proper irrigation scheduling to prevent dry or wet areas. If the precipitation rate is not known, the tendency is to overwater to be sure enough water is applied.

Sometimes there is a misconception about sprinkler run times and precipitation rates. The misconception is that sprinkler systems with low precipitation rates take longer to irrigate the landscape. While it is true that each head must be run for a longer period of time, more heads can be operated at one time and, therefore, the total irrigation time for an entire project will be the same for both high and low precipitation-rate sprinkler heads.

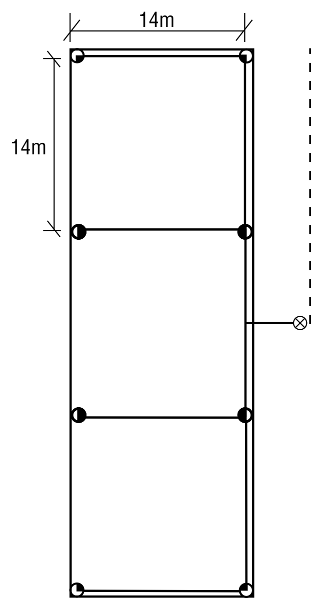
In the following illustration, two areas of the same size, one irrigated with high and one with low precipitation-rate sprinklers, both require the same amount of irrigation time. The water supply is 120 l/min; 7.20 m^3/hr and the plants require 6 mm/hr of water.

High Precipitation Rate (25 mm/hr)



◔ 20 l/min; 1.2 m^3/hr Quarter-circle Head
◐ 40 l/min; 2.4 m^3/hr Half-circle Head
⊗ Irrigation Control Valve
120 l/min; 7.2 m^3/hr TOTAL PER VALVE

Low Precipitation Rate (12 mm/hr)



◔ 10 l/min; 0.6 m^3/hr Quarter-circle Head
◐ 20 l/min; 1.2 m^3/hr Half-circle Head
⊗ Irrigation Control Valve
120 l/min; 7.2 m^3/hr TOTAL FOR ONE VALVE

In the high precipitation-rate example, two valves are required and each valve must be operated for 15 minutes in order to apply the 6 mm/hr of water needed. Total run time is 30 minutes.

In the low precipitation-rate example, the lower l/min or m^3/hr per head allows the entire area to be operated by one control valve. The lower precipitation rate requires that the heads be operated for 30 minutes but since all the heads are operated at the same time the total run time is the same as in the high precipitation-rate example.

With low or high precipitation-rate sprinkler systems, the total run time is limited by the volume (l/min or m^3/hr) available from the water source, not the precipitation rate of the sprinkler system.

Sprinkler System Cost and Precipitation Rates

Low precipitation-rate sprinkler systems often cost less to install than those with high precipitation rates. This is because low precipitation-rate sprinklers require lower flow rates (l/min or m^3/hr), per area irrigated, than high precipitation-rate sprinklers. This means fewer valves and controller stations are required, and therefore less overall system cost.

Determining Precipitation Rates

As mentioned earlier, there are two primary methods used to determine precipitation rate: the Sprinkler Spacing Method and the Total Area Method.

The Sprinkler Spacing Method

This method is used to determine the precipitation rate for a single sprinkler. The rate is calculated assuming the sprinkler is used in conjunction with other sprinklers of the same kind (i.e., same arc, flow, and spacing). With this method, one can compare the precipitation rate of similar types of sprinkler heads with each other. In the past, this formula was used for the Sprinkler Spacing Method:

$$P_r = \frac{60 \times \text{l/min (for } 360^\circ \text{ head)}}{\text{Head Spacing} \times \text{Row Spacing}}$$

$$P_r = \frac{1{,}000 \times \text{m}^3\text{/hr (for } 360^\circ \text{ head)}}{\text{Head Spacing} \times \text{Row Spacing}}$$

where:

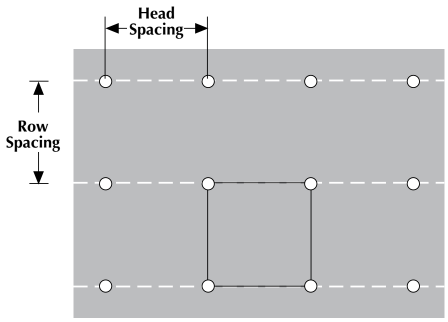
P_r is the precipitation rate in millimeters per hour.

60; 1,000 is a constant that converts liters per minute to millimeters per hour; m^3/hr to mm/hr.

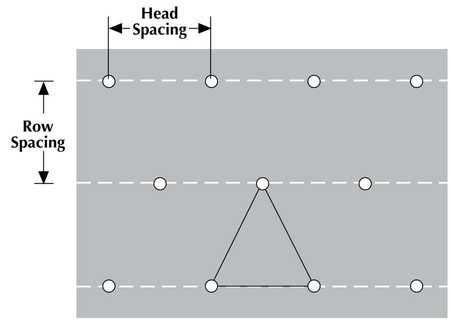
l/min or m^3/hr is the rated flow of the full-circle head used in liters per minute; cubic meters per hour.

Head Spacing is the distance in feet between heads in the same row (see the following diagram).

Row Spacing is the distance in meters between the rows of sprinklers (see the following diagram).



Square Spacing Pattern



Equilateral Triangular Spacing Pattern

While the previous formula has been in use for many years, it requires an additional calculation for sprinkler heads with spray arcs under 360 degrees. To simplify this process, we have modified the Sprinkler Spacing Method formula to be applicable to heads of any arc. The **modified** formula, which is now recommended, is:

$$P_r = \frac{21{,}600 \times \text{l/min (for any arc)}}{\text{Degrees of Arc} \times \text{Head Spacing} \times \text{Row Spacing}}$$

$$P_r = \frac{360{,}000 \times \text{m}^3\text{/hr (for any arc)}}{\text{Degrees of Arc} \times \text{Head Spacing} \times \text{Row Spacing}}$$

where:

P_r is the precipitation rate in millimiters per hour.

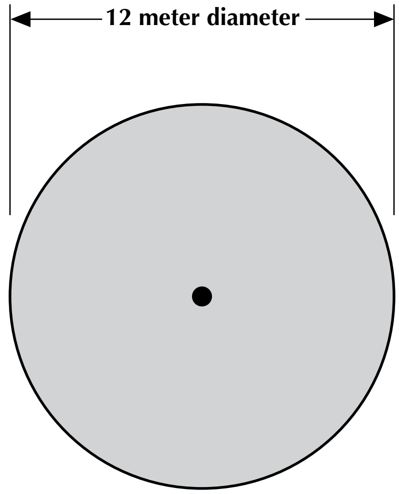
21,600; 360,000 is a constant that converts liters per minute; m^3/hr to millimeters per hour for sprinklers with any arc. It is derived from 60 min/hr divided by 1,000 liters per cubic meter, multiplied by 1,000 mm/meter times 360 degrees.

l/min or m^3/hr is the rated flow of the head used, regardless of its arc.

Degrees of Arc is the arc of the spray pattern, in degrees, for the sprinkler selected (e.g., full circle = 360˚, half circle = 180˚, etc.).

Head Spacing is the distance in meters between heads in the same row.

Row Spacing is the distance in meters between the rows of sprinklers.



Full-circle sprinkler at 20,0 l/min; 1,20 m³/hr

This illustration depicts a full-circle head with a coverage diameter of 12 meters (a 6 meter radius) that delivers 18.9 l/min; 1.11 m^3/hr over that circle. The manufacturer recommends a 6 meter head spacing and 6 meter between the rows of heads (i.e., square spacing).

Using the modified Sprinkler Spacing Method formula, we can determine the precipitation rate as follows:

$$P_r = \frac{21{,}600 \times \text{l/min (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$$

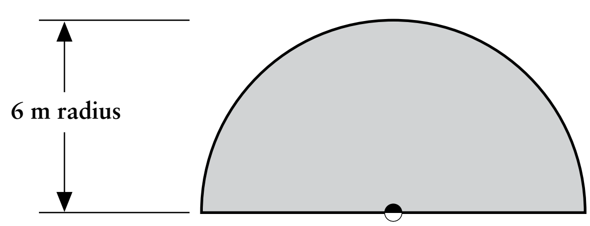
$$P_r = \frac{360{,}000 \times \text{m}^3\text{/hr (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$$

$$= \frac{21{,}600 \times 20 \text{ l/min}}{360 \times 6\text{m} \times 6\text{m}} \qquad = \frac{360{,}000 \times 1.20 \text{ m}^3\text{/hr}}{360 \times 6\text{m} \times 6\text{m}}$$

$$= \frac{432{,}000 \text{ l/min}}{12{,}960} \qquad = \frac{432{,}000 \text{ m}^3\text{/hr}}{12{,}960}$$

$$= 33 \text{ mm/hr} \qquad = 33 \text{ mm/hr}$$

This formula works equally well for sprinklers of any arc:



Half-circle sprinker at 10 l/min; 0.60 m³/hr

In this example, the head selected is a half-circle (180˚ arc) sprinkler with a 6 m radius delivering 10 l/min; 0.60 m^3/hr. The manufacturer recommends a 6 m head spacing and 6 meters between the rows of heads (square spacing). Using the modified Sprinkler Spacing Method, we can determine the precipitation rate as follows:

$$P_r = \frac{21{,}600 \times \text{l/min (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$$

$$P_r = \frac{360{,}000 \times \text{m}^3\text{/hr (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$$

$$= \frac{21{,}600 \times 10 \text{ l/min}}{180 \times 6\text{m} \times 6\text{m}} \qquad = \frac{360{,}000 \times 0.60 \text{ m}^3\text{/hr}}{180 \times 6\text{m} \times 6\text{m}}$$

$$= \frac{216{,}000 \text{ l/min}}{6{,}480} \qquad = \frac{216{,}000 \text{ m}^3\text{/hr}}{6{,}480}$$

$$= 33 \text{ mm/hr} \qquad = 33 \text{ mm/hr}$$

Notice the precipitation rate for both the full-circle head and the half-circle head is 33 mm/hr This is because the half-circle head covers half the area and applies half the flow of the full-circle head.

Sample Problems for the Sprinkler Spacing Method

Use the modified Sprinkler Spacing Method to determine precipitation rate in the following problems (the answers can be found on page 31).

1. The characteristics of the selected head are:
    - full-circle (360˚ arc) sprinkler
    - 13 l/min or 0.79 m^3/hr
    - 12 m radius
    - recommended head spacing is 12 m
    - recommended row spacing is 12 m (square spacing)
2. The characteristics of the selected head are:
    - quarter-circle (90˚ arc) sprinkler
    - 2 l/min or 0.12 m^3/hr
    - 5 m radius
    - recommended head spacing is 5 m
    - recommended row spacing is 4 m (equilateral triangular spacing)
3. The characteristics of the selected head are:
    - three-quarter-circle (270˚ arc) sprinkler
    - 6 l/min or 0.36 m^3/hr
    - 2 m radius
    - recommended head spacing is 3 m
    - recommended row spacing is 2 m (triangular spacing)
4. The characteristics of the selected head are:
    - one-third-circle (120˚ arc) sprinkler
    - 40 l/min or 2.4 m^3/hr
    - 18 m radius
    - recommended head spacing is 15 m
    - recommended row spacing is 17 m (rectangular spacing)

The Total Area Method

This calculation is best suited for determining the average precipitation rate for a system, or portion of a system, that uses sprinklers with differing arcs, flow rates, and spacings. The formula for the Total Area Method is:

$$P_r = \frac{60 \times \text{Total l/min}}{\text{Total Area (m}^2\text{)}}$$

$$P_r = \frac{1{,}000 \times \text{Total m}^3\text{/hr}}{\text{Total Area (m}^2\text{)}}$$

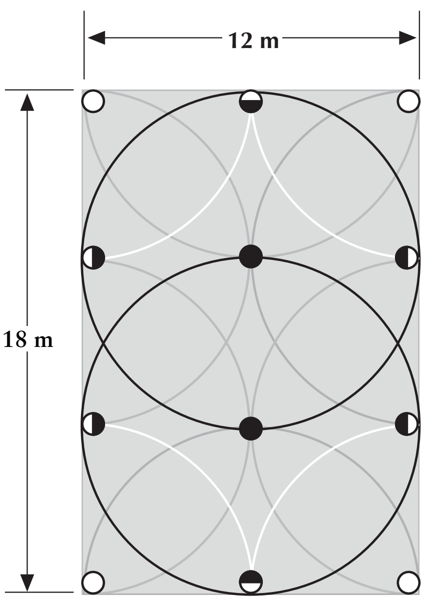
where:

P_r is the precipitation rate in millimeters per hour.

60; 1,000 is a constant that converts liters per minute to millimeters per hour.

l/min or m^3/hr is the rated flow of the full-circle head used in liters per minute; cubic meters per hour.

Total Area is the area irrigated, in square meters.



● Full-circle sprinkler at 30 l/min or 1.8 m^3/hr

◐ Half-circle sprinkler at 15 l/min or 0.9 m^3/hr

◔ Quarter-circle sprinkler at 7.5 l/min or 0.45 m^3/hr

Total l/min or m^3/hr

● 2 Full Circle x 30 l/min or 1.8 m^3/hr	= 60 l/min or 3.6 m^3/hr
◐ 6 Half Circle x 15 l/min or 0.9 m^3/hr	= 90 l/min or 5.4 m^3/hr
◔ 4 Quarter Circle x 7.5 l/min or 0.45 m^3/hr	= 30 l/min or 1.8 m^3/hr
Total	= 180 l/min or 10.8 m^3/hr

Total Area

12 m x 18 m = 216 m^2

In this illustration, the area under consideration contains 12 sprinkler heads with arcs varying from 90˚ to 360˚, with flow rates between 7.5 and 30 l/min or 0.45 m^3/hr, to 1.8 m^3/hr.

Using the Total Area Method formula, we can determine the precipitation rate as follows:

$$P_r = \frac{60 \times \text{Total l/min}}{\text{Total Area (m}^2\text{)}} \qquad P_r = \frac{1{,}000 \times \text{Total m}^3\text{/hr}}{\text{Total Area (m}^2\text{)}}$$

$$= \frac{60 \times 18 \text{ l/min}}{216 \text{ m}^2} \qquad = \frac{1{,}000 \times 10.8 \text{ m}^3\text{/hr}}{216 \text{ m}^2}$$

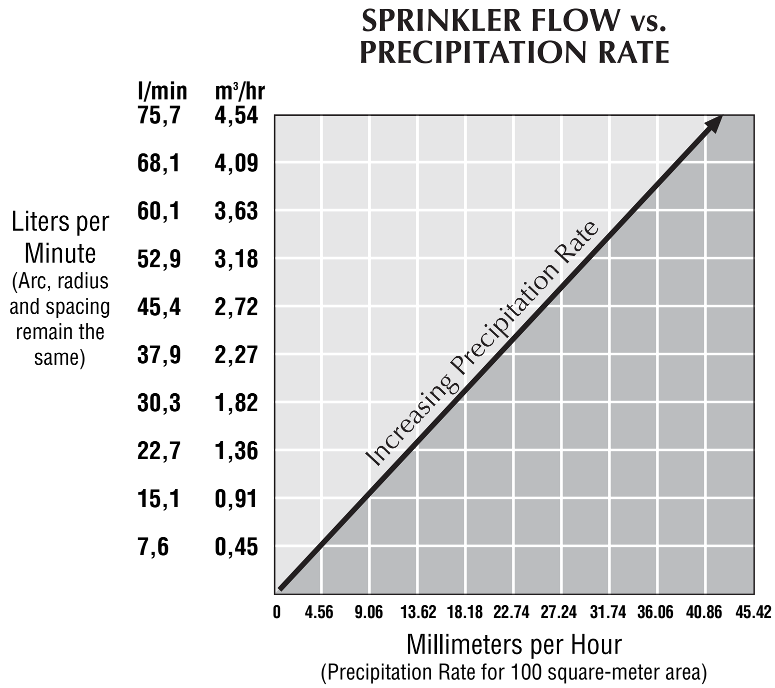
$$= 50 \text{ mm/hr} \qquad = 50 \text{ mm/hr}$$

Sample Problems for the Total Area Method

Use the Total Area Method to determine precipitation rate in the following problems (the answers can be found on page 32).

1. The characteristics of the selected area are:
   - total flow to the area is 95 l/min or 5.7 m^3/hr
   - total area irrigated is 195 m^2
2. The characteristics of the selected area are:
   - total flow to the area is 946 l/min or 56.7 m^3/hr
   - total area irrigated is ½ hectare (5,000 m^2)

The precipitation rate of a sprinkler or a system varies **directly** with the flow rate of the sprinkler (measured in l/min or m^3/hr). Because Precipitation Rate is a measurement of how fast water is being applied, if the spacing remains constant, **increasing** sprinkler flow **increases** the precipitation rate and **decreasing** sprinkler flow **decreases** the precipitation rate.



For example, if the sprinkler flow is doubled (by changing the head or nozzle), the precipitation rate will double, as shown by the following calculations.

Precipitation rate for a 180° head at 10 l/min; 0.6 m^3/hr spaced on a 6 m by 6 m square grid:

$$P_r = \frac{21{,}600 \text{ x l/min (for any arc)}}{\text{Arc (degrees) x Head Spacing x Row Spacing}}$$

$$= \frac{21{,}600 \text{ x } 10 \text{ l/min}}{180 \text{ x } 6 \text{ m x } 6 \text{ m}}$$

$$= \frac{216{,}000 \text{ l/min}}{6{,}480}$$

$$= 33 \text{ mm/hr}$$

$$P_r = \frac{360{,}000 \text{ x m}^3\text{/hr (for any arc)}}{\text{Arc (degrees) x Head Spacing x Row Spacing}}$$

$$= \frac{360{,}000 \text{ x } 0.6 \text{ m}^3\text{/hr}}{180 \text{ x } 6 \text{ m x } 6 \text{ m}}$$

$$= \frac{216{,}000 \text{ m}^3\text{/hr}}{6{,}480}$$

$$= 33 \text{ mm/hr}$$

Precipitation rate for a 180° head at 20 l/min; 1.2 m^3/hr spaced on a 6 m by 6 m square grid:

$$P_r = \frac{21{,}600 \times \text{l/min (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$$

$$= \frac{21{,}600 \times 20 \text{ l/min}}{180 \times 6 \text{ m} \times 6 \text{ m}}$$

$$= \frac{432{,}000 \text{ l/min}}{6{,}480}$$

$$= 66 \text{ mm/hr}$$

$$P_r = \frac{360{,}000 \times \text{m}^3\text{/hr (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$$

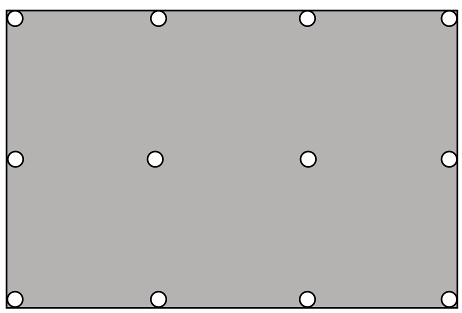
$$= \frac{360{,}000 \times 1.2 \text{ m}^3\text{/hr}}{180 \times 6 \text{ m} \times 6 \text{ m}}$$

$$= \frac{432{,}000 \text{ m}^3\text{/hr}}{6{,}480}$$

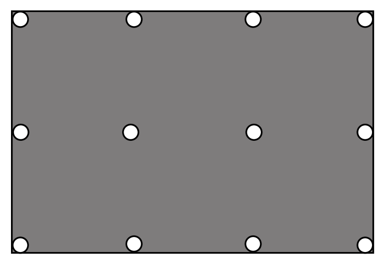
$$= 66 \text{ mm/hr}$$

Effect of Head and Row Spacing on Precipitation Rates

The precipitation rate of a sprinkler or system is inversely related to head spacing and row spacing. With the sprinkler flow remaining constant, **increasing** head or row spacing **decreases** the precipitation rate and, conversely, **reducing** head or row spacing **increases** the precipitation rate.



Correct head and row spacing for desired Precipitation Rate



Decreased head and row spacing increases Precipitation Rate

For example, if the sprinkler spacing along a row is reduced by one half (e.g. 6 m to 3 m), the precipitation rate would double, as shown by the following calculations.

Precipitation rate for heads on a 6 m by 6 m square grid:

$$P_r = \frac{21{,}600 \times \text{l/min (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$$

$$= \frac{21{,}600 \times 10 \text{ l/min}}{180 \times 6 \text{ m} \times 6 \text{ m}}$$

$$= \frac{216{,}000 \text{ l/min}}{6{,}480}$$

$$= 33 \text{ mm/hr}$$

$$P_r = \frac{360 \times \text{m}^3\text{/hr (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$$

$$= \frac{360{,}000 \times 0.6 \text{ m}^3\text{/hr}}{180 \times 6 \text{ m} \times 6 \text{ m}}$$

$$= \frac{216{,}000 \text{ m}^3\text{/hr}}{6{,}480}$$

$$= 33 \text{ mm/hr}$$

Precipitation rate if head spacing is reduced to 3 meters, with row spacing remaining at 6 meters:

$$P_r = \frac{21{,}600 \times \text{l/min (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$$

$$= \frac{21{,}600 \times 10 \text{ l/min}}{180 \times 3 \text{ m} \times 6 \text{ m}}$$

$$= \frac{216{,}000 \text{ l/min}}{3{,}240}$$

$$= 66 \text{ mm/hr}$$

$$P_r = \frac{360{,}000 \times \text{m}^3\text{/hr (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$$

$$= \frac{360{,}000 \times 0.6 \text{ m}^3\text{/hr}}{180 \times 3 \text{ m} \times 6 \text{ m}}$$

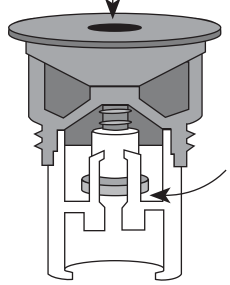
$$= \frac{216{,}000 \text{ m}^3\text{/hr}}{3{,}240}$$

$$= 66 \text{ mm/hr}$$

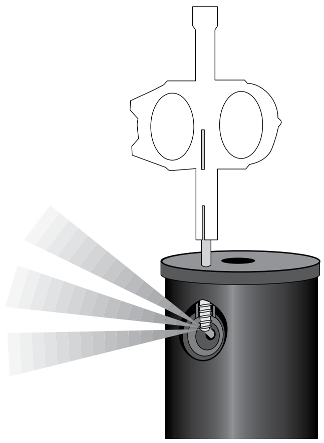
As stated, reducing head or row spacing increases the precipitation rate, and increasing head or row spacing decreases the precipitation rate.

Effect of Radius Adjustment on Precipitation Rate and Distribution Uniformity

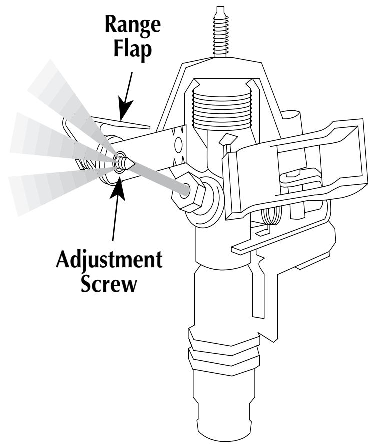
Radius adjustment of sprinkler heads is usually accomplished in one of two ways. The first method is an internal change of pressure and flow (l/min or m^3/hr); thus, modifying the radius of throw. This is accomplished on fixed-spray heads, fixed-stream spray heads and some rotating stream spray heads by turning an adjustment screw on the top of the head.



The second method involves external disruption of the spray with no change in flow but a modification in radius of throw. This is typical of rotor and impact heads, and is accomplished by screws, flaps, or pins that disturb the stream of water after it has left the nozzle orifice.



Gear-driven sprinkler with spray diffused



Impact Sprinkler with spray diffused

It is important to recognize the consequences of radius adjustment on how uniformly the sprinkler distributes water over the irrigated area. One method of describing this uniformity is called Distribution Uniformity. Distribution uniformity (DU) is a measurement of how evenly water is applied to an area. A perfect DU would mean all of the area irrigated received exactly the same amount of water. While desirable, this is virtually impossible to achieve.

Sprinkler manufacturers have designed their sprinklers to operate at peak performance at a given radius. Adjusting the radius below this optimum will reduce the distribution uniformity and lead to dry and wet spots. To understand the effect of radius adjustment on precipitation rate and distribution uniformity, one must consider that the precipitation rate is the *average* rate at which water is applied to an area—this does not take the distribution uniformity into account. For example, two sprinkler systems, both with a precipitation rate of 38 mm/hr have the same precipitation rate but they will not necessarily distribute the water in each area with the same uniformity.

Reducing the Radius

As an extreme example, suppose you have a zone of impact sprinklers, with a normal radius of throw of 12 meters, that are spaced 13 meters apart. Now suppose you reduce the radius to 6 meters. Since the head spacing was not changed, and radius reduction on impact heads does not reduce the flow (l/min or m^3/hr), the "precipitation rate" remains the same, but the distribution uniformity is much worse than before. **The precipitation rate did not change because the flow and spacing remained the same**. However, the distribution uniformity is much worse because now some areas are not receiving any water.

In another example with fixed-spray heads that have a radius of 4 meters and are spaced at 4 meters, suppose we reduce the radius from 4 to 2 meters. With fixed-spray heads, this reduces the flow of water along with the radius. In this case, **the precipitation rate is reduced because the flow (l/min or m^3/hr) was reduced (even though the spacing remained the same.)** Since the head spacing was not changed, the distribution uniformity would not be as good as before the radius was reduced.

Increasing the Radius

If increasing the radius does not include an increase in flow, or does not result in water being applied outside the landscaped area, then increasing the radius without increasing the spacing will not alter the precipitation rate.

Summary of Effect of Radius Adjustment on Precipitation Rate

Adjusting the radius will alter the system precipitation rate only if:

- head or row spacing is changed.
- flow is changed (this is dependent on sprinkler head design).
- some water previously being applied to the landscaped area is now falling on hardscape or outside the landscaped area (this would result in a slight reduction of the actual precipitation rate along the edges of the system).

Adjusting the sprinkler radius may also adversely affect the spray pattern uniformity and result in poor distribution uniformity and application efficiency.

Sample Problems: Precipitation Rate Versus Flow, Head/Row Spacing, and Radius Adjustment

Without using the slide rule or making manual calculations, in each of the following problems decide if the precipitation rate should: (A) increase, (B) decrease, or (C) remain the same. (The answers can be found on page 32.)

1. Head spacing is reduced from 9 meters to 8 meters. Row spacing, arc and l/min or m^3/hr from the heads remain the same.
2. l/min or m^3/hr from the head is reduced from 17 l/min or 1.02 m^3/hr to 15 l/min or 0.9 m^3/hr. Arc, head and row spacing remain the same.
3. Head spacing is increased from 8 meters to 9 meters. l/min or m^3/hr is reduced from 7.6 l/min or 0.45 m^3/hr to 6.4 l/min or 0.38 m^3/hr. Row spacing and arc remain the same.
4. The radius of the impact head is reduced with the range flap or screw. Arc, head and row spacing remain the same.
5. The radius is reduced on a fixed spray head by turning an internal flow adjustment screw. Arc, head and row spacing remain the same.
6. The radius is increased on a gear-drive rotor by turning the radius adjustment screw so it no longer interrupts the spray stream after it has left the sprinkler nozzle. Arc, head and row spacing remain the same.

Matched Precipitation Rates

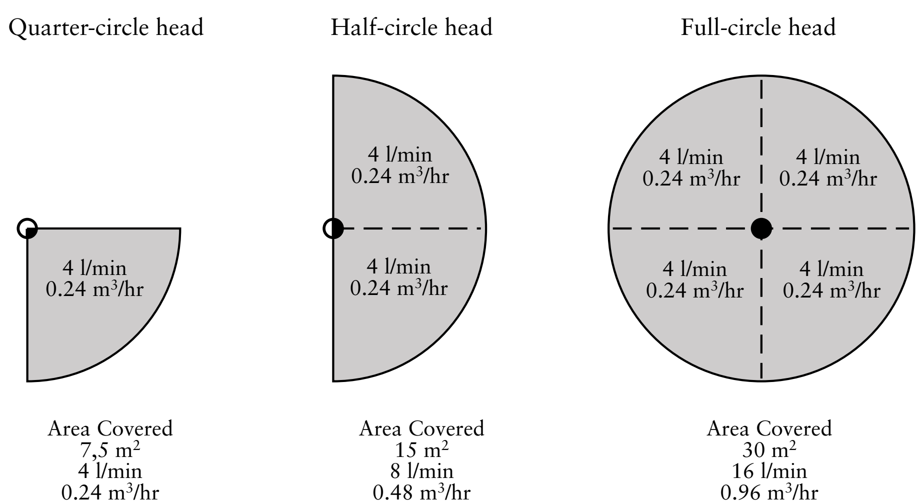
A system or zone in which all the heads have similar precipitation rates is said to have matched precipitation rates. A sprinkler by itself does not have a matched precipitation rate. Only when it is used with other sprinklers of similar precipitation rates would they be considered matched (matched implies two or more). When designing sprinkler systems, matching precipitation rates can help to avoid wet and dry spots and excessive run times which leads to high water bills, increased pumping costs, or both.

Both wet and dry areas can be caused by applying water at different precipitation rates. The area with the low precipitation rate becomes a dry spot and the area with the high precipitation rate becomes too wet. Where heads that apply water at substantially different precipitation rates must be used, they should be zoned separately—divided into circuits that are operated by different control valves. Separate control zones can be used to schedule an increase in run times for lower precipitation rate heads in order to equalize the amount of water applied.

Achieving Matched Precipitation Rates

As discussed earlier, head and row spacing directly affect precipitation rates. There are two other related factors that also affect precipitation rate: the head's arc of coverage and its flow rate in l/min or m^3/hr. (In this section, we assume that head and row spacing remain the same.) The following diagram depicts sprinklers with matched precipitation rates.

MATCHED PRECIPITATION RATE HEADS



With matched precipitation rates, as the arc of the sprinkler increases, the flow rate also increases. In the previous illustration, the half-circle head covers twice the area of the quarter-circle head, with a flow rate twice that of the quarter-circle head. The full-circle head covers twice the area of the half-circle head and four times the area of a quarter-circle head, and has a flow rate twice that of the half-circle head and four times that of the quarter-circle head.

If the heads in the example all have a 3 meter radius, the arc, area covered, and rate of flow for each would be:

Arc	Area covered by sprinkler	Flow
90˚	7.5 m^2	4 l/min or 0.24 m^3/hr
180˚	15 m^2	8 l/min or 0.48 m^3/hr
360˚	30 m^2	16 l/min or 0.96 m^3/hr

As the spray arc doubles, so does the flow. This is a quick way to check for matching precipitation-rate heads. The flow rate of half-circle heads must be two times the flow rate of the quarter-circle heads, and the full-circle heads must have two times the flow rate of the half-circle heads. Manufacturers' specifications often specifically indicate the sprinklers with doubling arcs and flow rates; i.e., the sprinklers considered to have matched precipitation rates.[3]

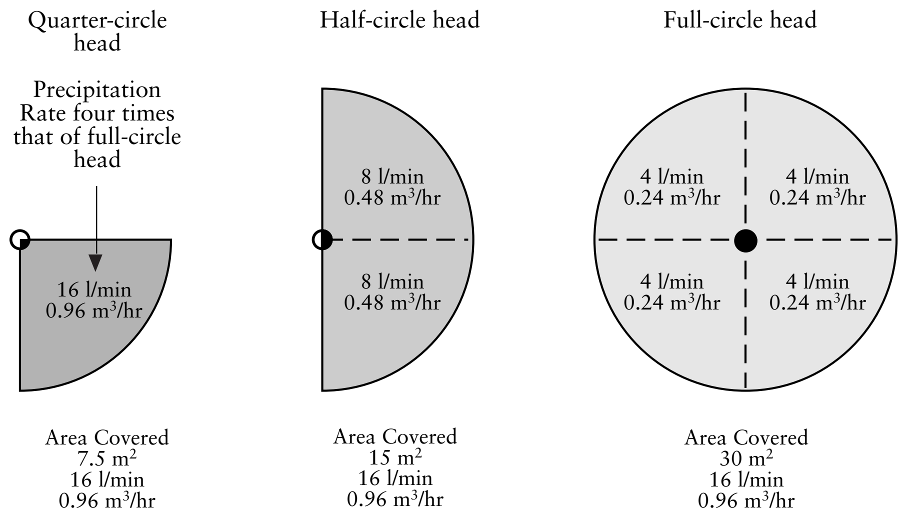
This principle can be applied to nozzle selection, as well as head selection. Sprinklers with multiple nozzle options can deliver matched precipitation rates if the installer follows the principle of doubling the flow as the arc doubles.

3 While exact doubling of flow rates is ideal, heads with l/min; m3/hr values within ±10% of the ideal would be considered to have matched precipitation rates.

A System Without Matched Precipitation Rates

The following illustration depicts three sprinklers with the same flow rate and three different arcs. (This would occur, for example, if the sprinklers all had the same nozzle installed regardless of arc.)

SPRINKLER HEADS THAT DO NOT HAVE MATCHED PRECIPITATION RATES



The area covered by the quarter-circle head is receiving four times as much water as the area covered by the full-circle head. If these heads were used on the same control valve, the areas covered by the quarter-circle heads would be too wet or the areas covered by the full-circle heads would be too dry. The use of sprinkler heads on the same valve with widely varying precipitation rates results in poor distribution uniformity and low system efficiency.

Sample Problems:
Identifying Matched Precipitation-Rate Heads

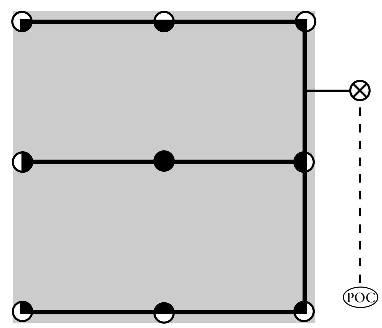
For each of the following problems, select the set of sprinklers with matching precipitation rates (the answers can be found on page 32).

1. Which set of sprinkler heads has matched precipitation rates?
   - A. Full-circle (360˚) head at 30 l/min or 1.8 m^3/hr, half-circle (180˚) head at 11 l/min or 0.66 m^3/hr, and quarter-circle (90˚) head at 6 l/min or 0.36 m^3/hr.
   - B. Full-circle (360˚) head at 61 l/min or 3.66 m^3/hr, half-circle (180˚) head at 30 l/min or 1.8 m^3/hr, and quarter-circle (90˚) head at 8 l/min or 0.48 m^3/hr.
   - C. Full-circle (360˚) head at 8 l/min or 0.48 m^3/hr, half-circle (180˚) head at 15 l/min or 0.9 m^3/hr, and quarter-circle (90˚) head at 30 l/min or 1.8 m^3/hr.
   - D. Full-circle (360˚) head at 8 l/min or 0.48 m^3/hr, half-circle (180˚) head at 4 l/min or 0,24 m^3/hr, and quarter-circle (90˚) head at 2 l/min or 0.12 m^3/hr.
   - E. None of the above have matched precipitation rates.
2. Which set of sprinkler heads has matched precipitation rates?
   - A. Full-circle (360˚) head at 14 l/min or 0.84 m^3/hr, half-circle (180˚) head at 7 l/min or 0.42 m^3/hr, and quarter-circle (90˚) head at 3.5 l/min or 0.21 m^3/hr.
   - B. Full-circle (360˚) head at 12 l/min or 0.72 m^3/hr, half-circle (180˚) head at 24 l/min or 1.44 m^3/hr, and quarter-circle (90˚) head at 48 l/min or 2.88 m^3/hr.
   - C. Full-circle (360˚) head at 23 l/min or 1.38 m^3/hr, half-circle (180˚) head at 15 l/min or 0.9 m^3/hr, and quarter-circle (90˚) head at 8 l/min or 0.48 m^3/hr.
   - D. Full-circle (360˚) head at 11 l/min or 0.66 m^3/hr, half-circle (180˚) head at 8 l/min or 0.48 m^3/hr, and quarter-circle (90˚) head at 4 l/min or 0.24 m^3/hr
   - E. None of the above have matched precipitation rates.

Proper Use of Matched Precipitation-Rate Heads

Use of matched precipitation-rate heads simplifies the design process by eliminating the need to separate full-circle heads from quarter-circle and half-circle heads. The following diagram illustrates the ability to mix sprinklers with various arcs or flow rates, on the same circuit, if they have matched precipitation rates.

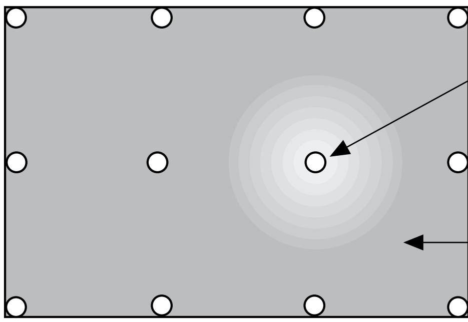
MATCHED PRECIPITATION RATE SYSTEM



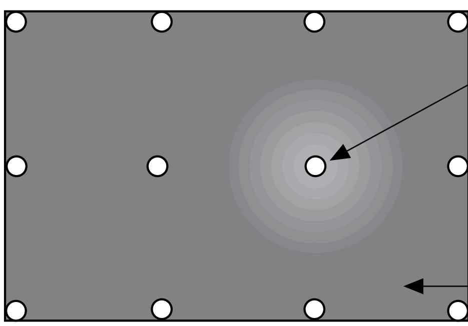
- ● 16 l/min or 0.96 m^3/hr Full-circle Head
- ◐ 8 l/min or 0.48 m^3/hr Half-circle Head
- ◔ 4 l/min or 0.24 m^3/hr Quarter-circle
- ⊗ Irrigation Control Valve
- - - Irrigation Main Line
- (POC) Point of Connection

The Dry Spot Drives the System

When heads that do not have matched precipitation rates are used in the same zone, dry spots develop, and dry spots usually lead to lengthening of sprinkler run times.[4] Since most turf managers or home owners are reluctant to allow dry areas of their lawn to die, the entire area is watered longer to ensure that sufficient water is applied to keep the dry spot alive.



In this diagram, one sprinkler has a different precipitation rate than the others, causing a "dry spot" to develop. The remaining area receives the minimum amount of water needed.



In order to apply the minimum amount of water needed to satisfy the "dry spot," all the remaining areas are over-watered.

[4] When scheduling irrigation, dry spots are measured by the "Scheduling Coefficient." The Scheduling Coefficient is an indication of the additional sprinkler run time necessary to compensate for dry spots.

Matched Precipitation Rates Using Multiple Nozzle Selections

The first heads to achieve matched precipitation rates were the spray heads with fixed arcs. As awareness of the importance of matched precipitation rates increased, the concept was incorporated into rotor heads through the use of multiple nozzle sets. With these sets, the designer or installer can select the nozzle combinations best suited for their design situation while maintaining a matched precipitation rate.

The selection of nozzles to achieve matched precipitation rates follows the same principles as those discussed for the fixed-arc heads. For heads with the same radius of throw, as the arc is increased, the flow rate of the sprinkler head should increase proportionally (quarter-circle head at 3.4 l/min; 0.2 m^3/hr, half-circle head at 7.6 l/min; 0.45 m^3/hr, etc.)

Referring to the following chart, the nozzles selected for matched precipitation rates could be as follows:

9 meter spacing at 3.4 bars or 344 kPa:

Quarter-circle	Half-circle	Full-circle
No. 2 Nozzle	No. 5 Nozzle	No. 8 Nozzle

12 meter spacing at 3.4 bars or 344 kPa:

Quarter-circle	Half-circle	Full-circle
No. 4 Nozzle	No. 7 Nozzle	No. 10 Nozzle

These nozzle combinations remain within our target range of a ±10% variation between precipitation rates for heads operated by the same control valve.

Performance Data
PGP Standard Nozzles – 25 Degree Trajectory

PGP Standard Nozzle (Red)
Performance Data

Nozzle	Pressure PSI	Radius ft.	Flow GPM	Precip in/hr ■	Precip in/hr ▲
1	30	28'	0.5	0.12	0.14
	40	29'	0.6	0.14	0.16
	50	**29'**	**0.7**	**0.16**	**0.19**
	60	30'	0.8	0.17	0.20
2	30	29'	0.7	0.16	0.19
	40	30'	0.8	0.17	0.20
	50	**30'**	**0.9**	**0.19**	**0.22**
	60	31'	1.0	0.20	0.23
3	30	30'	0.9	0.19	0.22
	40	31'	1.0	0.20	0.23
	50	**31'**	**1.2**	**0.24**	**0.28**
	60	32'	1.3	0.24	0.28
4	30	32'	1.2	0.23	0.26
	40	33'	1.4	0.25	0.29
	50	**34'**	**1.6**	**0.27**	**0.31**
	60	34'	1.8	0.30	0.35
5	30	34'	1.6	0.27	0.31
	40	36'	1.8	0.27	0.31
	50	**38'**	**2.0**	**0.27**	**0.31**
	60	38'	2.2	0.29	0.34
6	30	34'	2.0	0.33	0.38
	40	36'	2.4	0.36	0.41
	50	**38'**	**2.7**	**0.36**	**0.42**
	60	38'	2.9	0.39	0.45
7	30	34'	2.6	0.43	0.50
	40	38'	3.0	0.40	0.46
	50	**40'**	**3.4**	**0.41**	**0.47**
	60	40'	3.7	0.45	0.51
8	30	37'	3.2	0.45	0.52
	40	39'	3.7	0.47	0.54
	50	**41'**	**3.9**	**0.45**	**0.52**
	60	42'	4.6	0.50	0.58
9	30	38'	3.6	0.48	0.55
	40	41'	4.3	0.49	0.57
	50	**44'**	**5.2**	**0.52**	**0.60**
	60	45'	5.5	0.52	0.60
10	40	44'	6.0	0.60	0.69
	50	46'	6.8	0.62	0.71
	60	**47'**	**7.6**	**0.66**	**0.76**
	70	49'	8.2	0.66	0.76
11	40	46'	8.0	0.73	0.84
	50	48'	8.9	0.74	0.86
	60	**50'**	**9.8**	**0.75**	**0.87**
	70	51'	10.5	0.78	0.90
12	40	46'	10.5	0.96	1.10
	50	48'	11.9	0.99	1.15
	60	**50'**	**12.7**	**0.98**	**1.13**
	70	52'	14.1	1.00	1.16

Note: All precipitation rates calculated for 180 degree operation.
For the precipitation rate for a 360 degree sprinkler, divide by 2.

PGP Standard Nozzle (Red)
Performance Data – Metric

Nozzle	Pressure Bars	Pressure kPa	Radius m	Flow m^3/hr	Flow l/min	Precip mm/hr ■	Precip mm/hr ▲
1	2.1	206	8.5	0.11	1.9	3	4
	2.8	275	8.8	0.14	2.3	3	4
	3.4	**344**	**8.8**	**0.16**	**2.7**	**4**	**5**
	4.1	413	9.1	0.18	3.0	4	5
2	2.1	206	8.8	0.16	2.6	4	5
	2.8	275	9.1	0.18	3.0	4	5
	3.4	**344**	**9.1**	**0.20**	**3.4**	**5**	**6**
	4.1	413	9.4	0.23	3.8	5	6
3	2.1	206	9.1	0.20	3.4	5	6
	2.8	275	9.4	0.23	3.8	5	6
	3.4	**344**	**9.4**	**0.27**	**4.5**	**6**	**7**
	4.1	413	9.8	0.30	4.9	6	7
4	2.1	206	9.8	0.27	4.5	6	7
	2.8	275	10.1	0.32	5.3	6	7
	3.4	**344**	**10.4**	**0.36**	**6.1**	**7**	**8**
	4.1	413	10.4	0.41	6.8	8	9
5	2.1	206	10.4	0.36	6.1	7	8
	2.8	275	11.0	0.41	6.8	7	8
	3.4	**344**	**11.6**	**0.45**	**7.6**	**7**	**8**
	4.1	413	11.6	0.50	8.3	7	9
6	2.1	206	10.4	0.45	7.6	8	10
	2.8	275	11.0	0.55	9.1	9	10
	3.4	**344**	**11.6**	**0.61**	**10.2**	**9**	**11**
	4.1	413	11.6	0.66	11.0	10	11
7	2.1	206	10.4	0.59	9.8	11	13
	2.8	275	11.6	0.68	11.4	10	12
	3.4	**344**	**12.2**	**0.77**	**12.9**	**10**	**12**
	4.1	413	12.2	0.84	14.0	11	13
8	2.1	206	11.3	0.73	12.1	11	13
	2.8	275	11.9	0.84	14.0	12	14
	3.4	**344**	**12.5**	**0.89**	**14.8**	**11**	**13**
	4.1	413	12.8	1.04	17.4	13	15
9	2.1	206	11.6	0.82	13.6	12	14
	2.8	275	12.5	0.98	16.3	13	14
	3.4	**344**	**13.4**	**1.18**	**19.7**	**13**	**15**
	4.1	413	13.7	1.25	20.8	13	15
10	2.8	275	13.4	1.36	22.7	15	17
	3.4	344	14.0	1.54	25.7	16	18
	4.1	**413**	**14.3**	**1.73**	**28.8**	**17**	**19**
	4.8	482	14.9	1.86	31.0	17	19
11	2.8	275	14.0	1.82	30.3	18	21
	3.4	344	14.6	2.02	33.7	19	22
	4.1	**413**	**15.2**	**2.23**	**37.1**	**19**	**22**
	4.8	482	15.5	2.39	39.7	20	23
12	2.8	275	14.0	2.38	39.7	24	28
	3.4	344	14.6	2.70	45.0	25	29
	4.1	**413**	**15.2**	**2.88**	**48.1**	**25**	**29**
	4.8	482	15.8	3.20	53.4	25	29

Note: All precipitation rates calculated for 180 degree operation.
For the precipitation rate for a 360 degree sprinkler, divide by 2.

Data represent test results in zero wind. Adjust for local conditions,
radius may be reduced up to 25% with adjustment screw
(this may alter the uniformity of the spray pattern)
Optimum performance is shown in bold type.

Selecting Nozzles for Odd-Arc Heads

With multiple nozzle selection it is possible to match precipitation rates in odd arcs as well. For example, full-circle G-Type heads with No. 8 nozzles, spaced 10.7 m apart at 344 kPa or 3.4 bars, have flow rates of 15.9 l/min or 0.95 m^3/hr each. A 270˚ head is needed on the same valve. Follow the steps below to determine the proper nozzle.

To match the precipitation rate of one spray arc with another, first determine the appropriate flow rate for the desired arc using the following formula:

$$\text{l/min}_x = (\text{Arc}_x/\text{Arc}_a) \times \text{l/min}_a$$

$$\text{m}^3/\text{hr}_x = (\text{Arc}_x/\text{Arc}_a) \times \text{m}^3/\text{hr}_a$$

where:

l/min or m^3/hr$_x$ is the flow rate (in l/min or m^3/hr) of the new head.

Arc$_x$ is the arc (in degrees) of the new head.

Arc$_a$ is the arc (in degrees) of the existing head.

l/min$_a$ or m^3/hr$_a$ is the flow rate (in l/min or m^3/hr) of the existing head.

For the previous example, the calculation would be:

$\text{l/min}_x = (\text{Arc}_x/\text{Arc}_a) \times \text{l/min}_a$	$\text{m}^3/\text{hr}_x = (\text{Arc}_x/\text{Arc}_a) \times \text{m}^3/\text{hr}_a$
= (270/360) x 15.9 l/min	= (270 /360) x 0.95 m^3/hr
= 0.75 x 15.9 l/min	= 0.75 x 0.95 m^3/hr
= 11.9 l/min	= 0.7 m^3/hr

With this rate of flow (11.9 l/min or 0.71 m^3/hr), you can check the nozzle performance chart to find the nozzle which most closely matches the desired l/min or m^3/hr. In this case, it would be a No. 7 nozzle with 12.9 l/min or 0.77 m^3/hr at 3.4 bars or 344 kPa. While this does not match our target l/min or m^3/hr exactly, it will provide a precipitation rate of 9 mm/hr for the 270˚ head, versus 8 mm/hr for the full-circle head. This precipitation rate remains within our target range of a ±10% variance.

Sample Problems:
Selecting Nozzles for Matched Precipitation Rates

For these problems, use the Nozzle Performance Chart shown in the previous section to select the appropriate nozzle for the desired arc to match the existing arc/nozzle combination. (The answers to these sample problems can be found on page 33.)

1. The existing heads are full-circle heads (360˚) spaced 14.9 m apart, using No. 10 nozzles (28.8 l/min or 1.73 m^3/hr) at 4.1 bars or 413 kPa. You need to add a 270˚ head to the same circuit. Find the nozzle that will match (within ±10%) the existing precipitation rate of 8 mm/hr.
2. The existing heads are half-circle heads (180˚) spaced 11.6 m apart, using No. 5 nozzles (7.6 l/min or 0.45 m^3/hr) at 3.4 bars or 344 kPa. You need to add a 110˚ head to the same circuit. Find the nozzle that will match (within ±10%) the existing precipitation rate of 7 mm/hr.
3. The existing heads are half-circle heads (180˚) spaced 12.2 m apart, using No. 6 nozzles (11 l/min or 0.66 m^3/hr) at 4.1 bars or 413 kPa. You need to add a 270˚ head to the same circuit. Find the nozzle that will match (within ±10%) the existing precipitation rate of 9 mm/hr.

Summary

Precipitation Rate

A. How fast water is applied, as measured in millimeters per hour.

B. An amount of water applied over a period of time, usually measured in millimiters per hour.

Sprinkler Precipitation Rate

When the precipitation rate for a "sprinkler" is given, it refers to the precipitation rate of a group of heads used together and all having the same arc, spacing and l/min or m^3/hr.

System Precipitation Rate

The precipitation rate for a "system" is the average precipitation rate of all sprinklers in a given area regardless of the arc, spacing, or flow rate of each head.

Use of Precipitation Rates in Landscape Irrigation

Sprinkler Head Selection

Scheduling Sprinkler Run Time

Effect of Sprinkler Flow Rate on Precipitation Rate

The precipitation rate of a sprinkler or system varies directly with the flow rate (in l/min or m^3/hr) of the sprinkler. When sprinkler spacing remains constant, increasing sprinkler l/min or m^3/hr increases the precipitation rate, and decreasing sprinkler l/min or m^3/hr decreases the precipitation rate.

Effect of Head/Row Spacing on Precipitation Rate

The precipitation rate of a sprinkler or system varies inversely with head and row spacing. When sprinkler l/min or m^3/hr remains the same, decreasing head or row spacing increases precipitation rate, while increasing head or row spacing decreases precipitation rate.

Effect of Radius Adjustment on Precipitation Rate

Adjusting the radius of a sprinkler head will affect the precipitation rate only if one of the following occur: (1) head or row spacing is changed, (2) flow is changed (this is dependent on sprinkler head design), or (3) some water previously being applied to the landscaped area is now falling on hardscape or outside the landscaped area.

Matched Precipitation Rate

A system (or zone) with a matched precipitation rate is one in which all the heads have similar precipitation rates.

Answers to Sample Problems

Answers to the Sprinkler Spacing Method problems (page 10):

1. $P_r = \dfrac{21{,}600 \times \text{l/min (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$

$= \dfrac{21{,}600 \times 13 \text{ l/min}}{360 \times 12 \text{ m} \times 12 \text{ m}}$

$= \dfrac{280{,}800 \text{ l/min}}{51{,}840}$

$= 5 \text{ mm/hr}$

$P_r = \dfrac{360{,}000 \times \text{m}^3\text{/hr (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$

$= \dfrac{360{,}000 \times 0.78 \text{ m}^3\text{/hr}}{360 \times 12 \text{ m} \times 12 \text{ m}}$

$= \dfrac{280{,}800 \text{ m}^3\text{/hr}}{51{,}840}$

$= 5 \text{ mm/hr}$

2. $P_r = \dfrac{21{,}600 \times \text{l/min (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$

$= \dfrac{21{,}600 \times 2 \text{ l/min}}{90 \times 5 \text{ m} \times 4 \text{ m}}$

$= \dfrac{43{,}200 \text{ l/min}}{1{,}800}$

$= 24 \text{ mm/hr}$

$P_r = \dfrac{360{,}000 \times \text{m}^3\text{/hr (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$

$= \dfrac{360{,}000 \times 0.12 \text{ m}^3\text{/hr}}{90 \times 5 \text{ m} \times 4 \text{ m}}$

$= \dfrac{43{,}200 \text{ m}^3\text{/hr}}{1{,}800}$

$= 24 \text{ mm/hr}$

3. $P_r = \dfrac{21{,}600 \times \text{l/min (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$

$= \dfrac{21{,}600 \times 6 \text{ l/min}}{270 \times 3 \text{ m} \times 2 \text{ m}}$

$= \dfrac{129{,}600 \text{ l/min}}{1{,}620}$

$= 80 \text{ mm/hr}$

$P_r = \dfrac{360{,}000 \times \text{m}^3\text{/hr (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$

$= \dfrac{360{,}000 \times 0.36 \text{ m}^3\text{/hr}}{270 \times 3 \text{ m} \times 2 \text{ m}}$

$= \dfrac{129{,}600 \text{ m}^3\text{/hr}}{1{,}620}$

$= 80 \text{ mm/hr}$

4. $P_r = \dfrac{21{,}600 \times \text{l/min (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$

$= \dfrac{21{,}600 \times 40 \text{ l/min}}{120 \times 15 \text{ m} \times 17 \text{ m}}$

$= \dfrac{864{,}000 \text{ l/min}}{30{,}600}$

$= 28 \text{ mm/hr}$

$P_r = \dfrac{360{,}000 \times \text{m}^3\text{/hr (for any arc)}}{\text{Arc (degrees)} \times \text{Head Spacing} \times \text{Row Spacing}}$

$= \dfrac{360{,}000 \times 2.4 \text{ m}^3\text{/hr}}{120 \times 15 \text{ m} \times 17 \text{ m}}$

$= \dfrac{864{,}000 \text{ m}^3\text{/hr}}{30{,}600}$

$= 28 \text{ mm/hr}$

Answers to the Total Area Method problems (page 12):

1. $P_r = \frac{60 \text{ x l/min}}{\text{Total Area m}^2}$

$= \frac{60 \text{ x } 95 \text{ l/min}}{195 \text{ m}^2}$

$= \frac{5{,}700 \text{ l/min}}{195 \text{ m}^2}$

$= 29 \text{ mm/hr}$

$P_r = \frac{1{,}000 \text{ x m}^3\text{/hr}}{\text{Total Area m}^2}$

$= \frac{1{,}000 \text{ x } 5.7 \text{ m}^3\text{/hr}}{195 \text{ m}^2}$

$= \frac{5{,}700 \text{ m}^3\text{/hr}}{195 \text{ m}^2}$

$= 29 \text{ mm/hr}$

2. $P_r = \frac{60 \text{ x l/min}}{\text{Total Area}}$

$= \frac{60 \text{ x } 946 \text{ l/min}}{5{,}000 \text{ m}^2}$

$= \frac{56{,}760 \text{ l/min}}{5{,}000 \text{ m}^2}$

$= 11 \text{ mm/hr}$

$P_r = \frac{1{,}000 \text{ x m}^3\text{/hr}}{\text{Total Area}}$

$= \frac{1{,}000 \text{ x } 56.7 \text{ m}^3\text{/hr}}{5{,}000 \text{ m}^2}$

$= \frac{56{,}700 \text{ m}^3\text{/hr}}{5{,}000 \text{ m}^2}$

$= 11 \text{ mm/hr}$

Answers to the precipitation rate versus flow and spacing problems (page 19):

1. Precipitation rate will increase.
2. Precipitation rate will decrease.
3. Precipitation rate will decrease.
4. Precipitation rate will remain the same.
5. Precipitation rate will decrease.
6. Precipitation rate will remain the same for most areas unless over-spray occurs along the perimeter of the irrigated area.

Answers to the identification of matched precipitation-rate head problems (page 23):

1. D.
2. A.

Answers to the nozzle selection for matched precipitation-rate problems (on page 29):

1. First find the appropriate rate of flow (l/min or m^3/hr) for the 270˚ head:

$l/min_x = (Arc_x/Arc_a) \times l/min_a$ **$m^3/hr_x = (Arc_x/Arc_a) \times m^3/hr_a$**

= (270 /360) x 28.8 l/min	= (270 /360) x 1.73 m^3/hr
= 0.75 x 28.8 l/min	= 0.75 x 1.73 m^3/hr
= 21.6 l/min	= 1.29 m^3/hr

Next use the performance chart to find the nozzle that most closely matches 21.6 l/min or 1.29 m^3/hr at the existing sprinkler operating pressure (4.1 bars or 413 kPa). The Standard No. 9 nozzle delivers 22.7 l/min or 1.36 m^3/hr (4.1 bars or 413 kPa). This is the flow rate closest to our target of 21.6 l/min or 1.29 m^3/hr. With this nozzle, the precipitation rate for a 270˚ head spaced 14.9 m apart, with a flow of 21.6 l/min or 1.29 m^3/hr, produces the desired precipitation rate, 8 mm/hr.

2. First find the appropriate rate of flow (l/min or m^3/hr) for the 110˚ head:

$l/min_x = (Arc_x/Arc_a) \times l/min_a$ **$m^3/hr_x = (Arc_x/Arc_a) \times m^3/hr_a$**

= (110 /180) x 7.6 l/min	= (110 /180) x 0.45 m^3/hr
= 0.61 x 7.6 l/min	= 0.61 x 0.45 m^3/hr
= 4.6 l/min	= 0.27 m^3/hr

Next use the performance chart to find the nozzle that most closely matches 4.6 l/min or 0.27 m^3/hr at the existing sprinkler operating pressure (3.4 bars or 344 kPa). The Standard No. 3 nozzle delivers 4.5 l/min or 0.27 m^3/hr at 3.4 bars or 344 kPa. When spaced 11 m apart, the precipitation rate for the No. 3 nozzle would be 7 mm/hr, which is within ±10% of the target of 7 mm/hr.

3. First find the appropriate rate of flow (l/min or m^3/hr) for the 270˚ head:

$$l/min_x = (Arc_x/Arc_a) \times l/min_a \qquad m3/hr_x = (Arc_x/Arc_a) \times m^3/hr_a$$

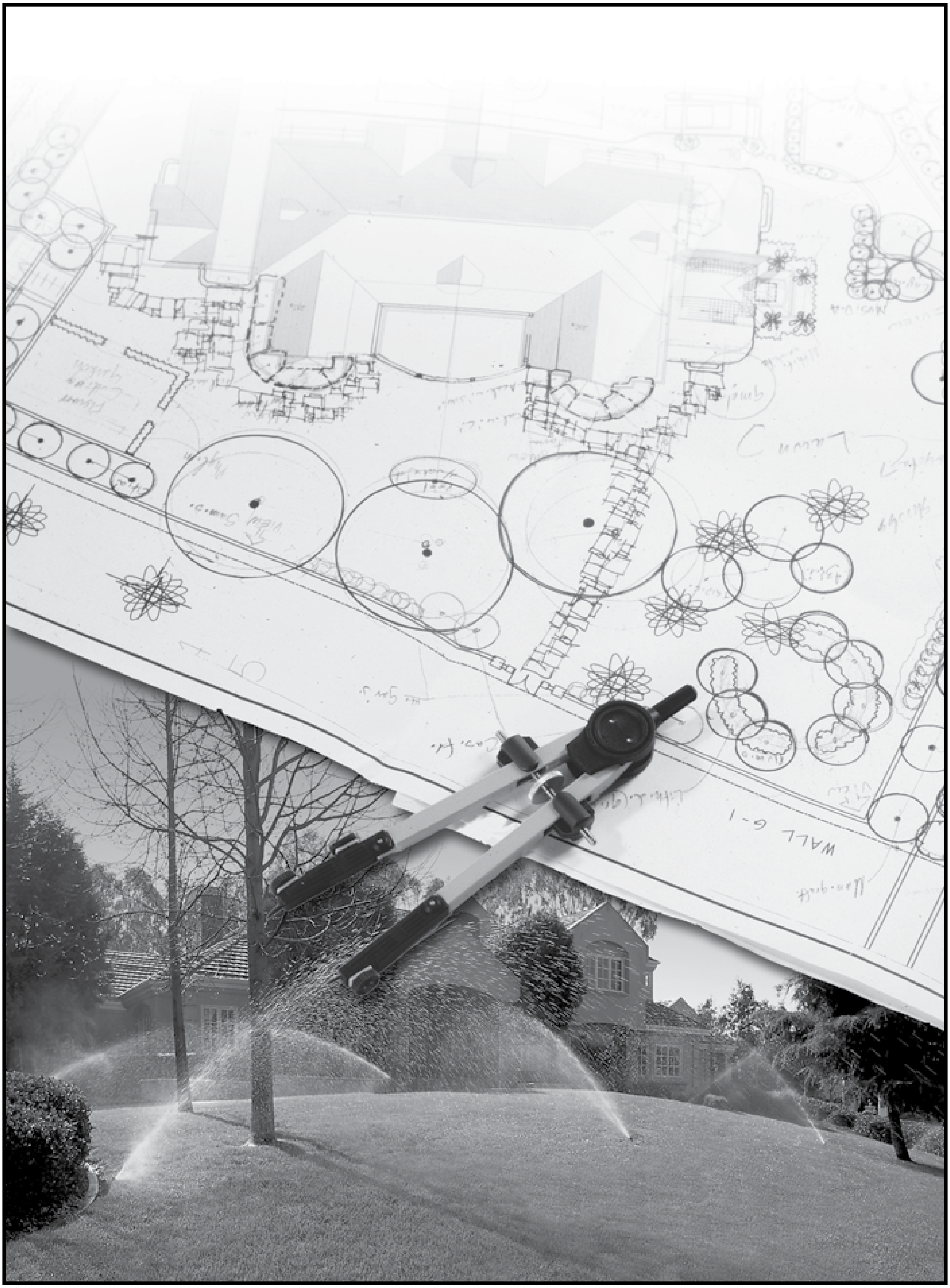
$$= (270/180) \times 11 \text{ l/min} \qquad = (270/180) \times 0.66 \text{ m}^3\text{/hr}$$

$$= 1.5 \times 11 \text{ l/min} \qquad = 1.5 \times 0.66 \text{ m}^3\text{/hr}$$

$$= 16.5 \text{ l/min} \qquad = 0.99 \text{ m}^3\text{/hr}$$

Next use the performance chart to find the nozzle that most closely matches 16.5 l/min or 0.99 m^3/hr at the existing sprinkler operating pressure (4.1 bars or 413 kPa). The Standard No. 8 nozzle delivers 17.4 l/min or 1.04 m^3/hr at 4.1 bars or 413 kPa. When spaced 12 m apart, the precipitation rate for the No. 8 nozzle would be 10 mm/hr, which is within ±10% of the target of 9 mm/hr.

Notes



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