4

Design and Layout of Sprinkler Irrigation System

Before proceeding with the sprinkler design and layout, some general principles or rules for good design must be followed. The basic objective of the overall good design is that, the system should provide a satisfactory uniform distribution of water with minimum annual operating cost, including depreciation, power cost and labor cost.

Sprinkler system design involves identifying alternative layout of the lateral, sub mains and mainlines for the farm and then developing design specifications for the most feasible layout. The layout is also dependant on the location of the water source and quantity of water available for irrigation. The design of the system should be suitable for a particular site and crop. The designed system should give high irrigation efficiency in its performance and economy.

4.1 Hydraulic Design of Sprinkler Systems

In sprinkler irrigation water is conveyed along the pipeline under pressure, a part of the pressure developed at the initial end is lost by the friction in the pipes. The sizes and types of laterals and main pipe selected should be such that the pressure loss due to friction for a given rate of flow remains within permissible limits.

The basic objective of hydraulic design of sprinklers is to obtain uniform distribution of water with desired rate of application, the break-up of jet with small drop size are essential to minimize the structural deterioration of the soil surface. At the same time to reduce the energy requirement for system operation and to

$$q = \left(\frac{\pi}{4}d_1^2 + \frac{\pi}{4}d_2^2\right)\left(C_d\sqrt{2gh}\right)$$

$$q = (d_1^2 + d_2^2)\left(\frac{\pi}{4}C_d\sqrt{2gh}\right)$$

where, a_1 = cross sectional area of large nozzle, m^2

a_2 = cross sectional area of small nozzle, m^2

d_1 = diameter of large nozzle, m

d_2 = diameter of small nozzle, m

Example 1. *Determine the theoretical discharge of sprinkler nozzle of size 3.0 × 2.5 mm at a operating pressure of 2.0 kg/cm².*

Solution:

Given data,

Diameter of large nozzle = 3.0 mm = 0·003 m;

Diameter of small nozzle = 2·5 mm = 0·0025 m

Operating pressure = 2.0 kg/cm²=20 m

Assuming C_d as 0.95 and using the orifice flow equation,

$$q = q_1 + q_2$$

$$q = C_d a_1\sqrt{2gh} + C_d a_2\sqrt{2gh}$$

$$q = (a_1 + a_2)\left(C_d\sqrt{2gh}\right)$$

$$q = \left(\frac{\pi}{4}d_1^2 + \frac{\pi}{4}d_2^2\right)\left(C_d\sqrt{2gh}\right)$$

$$q = (d_1^2 + d_2^2)\left(\frac{\pi}{4}C_d\sqrt{2gh}\right)$$

$$q = (0.003^2 + 0.0025^2)\left(\frac{\pi}{4}0.95\sqrt{2\times 9.8\times 20}\right)$$

$$q = 0.000225\,m^3/sec = 0.81\,m^3/hr = 0.225\,lit/sec$$

Example 2. *Determine the diameter of sprinkler nozzle having discharge of 2.85 m³/hr with operating pressure of 4.0 kg/cm². (Assume coefficient of discharge, C_d=0.95)*

Solution:

Given,

Sprinkler discharge, q = 2.85m³/hr = 7.9 $\times 10^{-4}$ m³/sec

Operating pressure, $h = 4.0$ kg/cm^2 = 40 m

Using orifice flow equation,

$$q = C_d\, a \sqrt{2gh}$$

$$7{\cdot}9 \times 10^{-4} = 0{\cdot}95 a \sqrt{2 \times 9{\cdot}8 \times 40}$$

$$a = 0{\cdot}2969 \times 10^{-4}, \text{ But } a = \frac{\pi}{4} d^2$$

$$\therefore \quad 0{\cdot}2969 \times 10^{-4} = \frac{\pi}{4} d^2$$

$$\therefore \quad d = 0{\cdot}00615 \text{ m} = 6{\cdot}15 \text{ mm}$$

Referring to the Appendix 3A, the commonly available large single sprinkler nozzle is of 6 mm or twin nozzle sprinkler size can be 5.5 mm × 3.2 mm (Refer Appendix 3B).

4.1.3 Recommended pressure and discharge for nozzle size

In general over a wide range the relationship between pressure head and discharge from the sprinkler can be expressed by, (Keller, *et. al.* 1974),

$$q = K_d \cdot H^x \qquad \ldots 4.4$$

where,

q = sprinkler discharge or flow, lit/hr

K_d = appropriate discharge coefficient for sprinkler and nozzle combined and the specific units used

H = sprinkler operating pressure, m

x = discharge exponent, usually 0·5 for sprinklers and micro-sprayers.

Discharge coefficient (K_d) decreases slightly with increase in sprinkler operating pressure consequently increase in q. However, for practical purpose it is considered constant for a particular range of operating pressure (H). The value of K_d can be worked out from the pressure discharge relationship or if two discharges are known for corresponding two operating pressure as given below (Fig. 4.1),

We have,

$$q = K_d \cdot H^x$$

Taking log of both sides for two discharges q_1 and q_2 at tow operating pressure H_1 and H_2

$$\log q_1 = \log K_d + x.\log H_1 \qquad \ldots 4.5$$

$$\log q_2 = \log K_d + x.\log H_2 \qquad \ldots 4.6$$

subtracting eq.4.5 from eq. 4.6,

maximize the area of coverage, following principles are involved in hydraulic design of a sprinkler system:

1. Calculation of discharge from the sprinkler nozzle.
2. Recommended pressure and discharge for nozzle size.
3. Determination of water spread area of sprinkler.
4. Determination of index for jet break up and drop size.
5. Intake and optimum application rate.

4.1.1 Discharge from a sprinkler nozzle

The theoretical discharge of a sprinkler nozzle may be computed from the orifice flow equation

$$q = C_d a \sqrt{2gh} \quad ...4.1$$

where,

q = nozzle discharge, m^3/sec

a = cross sectional area of sprinkler nozzle, m^2

h = pressure head at the nozzle, m

C_d = coefficient of discharge which is a function of friction and contraction losses

g = acceleration due to gravity, m/sec^2

The coefficient of discharge for well-designed, small nozzles varies from about 0.95 to 0.98. Some nozzles have coefficients as low as 0.80. Normally, the larger the nozzle, the lower is the coefficient, where the sprinkler has two nozzle, the total discharge is the combined capacity of both.

4.1.2 Discharge from twin sprinkler nozzle

Total discharge of twin sprinkler nozzle can be calculated by adding the discharge from the two nozzles on the sprinkler head,

$$q = q_1 + q_2$$

where,

q_1 = discharge from large nozzle

q_2 = discharge from small nozzle

$$q = C_d a_1 \sqrt{2gh} + C_d a_2 \sqrt{2gh}$$

$$q = (a_1 + a_2)\left(C_d \sqrt{2gh}\right)$$

$$\log q_2 - \log q_1 = x.\log H_2 - x.\log H_1$$

$$x = \frac{\log q_2 - \log q_1}{\log H_2 - \log H_1} \quad \text{...4.7}$$

$$x = \frac{\log\left(\frac{q_2}{q_1}\right)}{\log\left(\frac{H_2}{H_1}\right)} \quad \text{...4.8}$$

and

$$K_d = \frac{q}{H^x} \quad \text{...4.9}$$

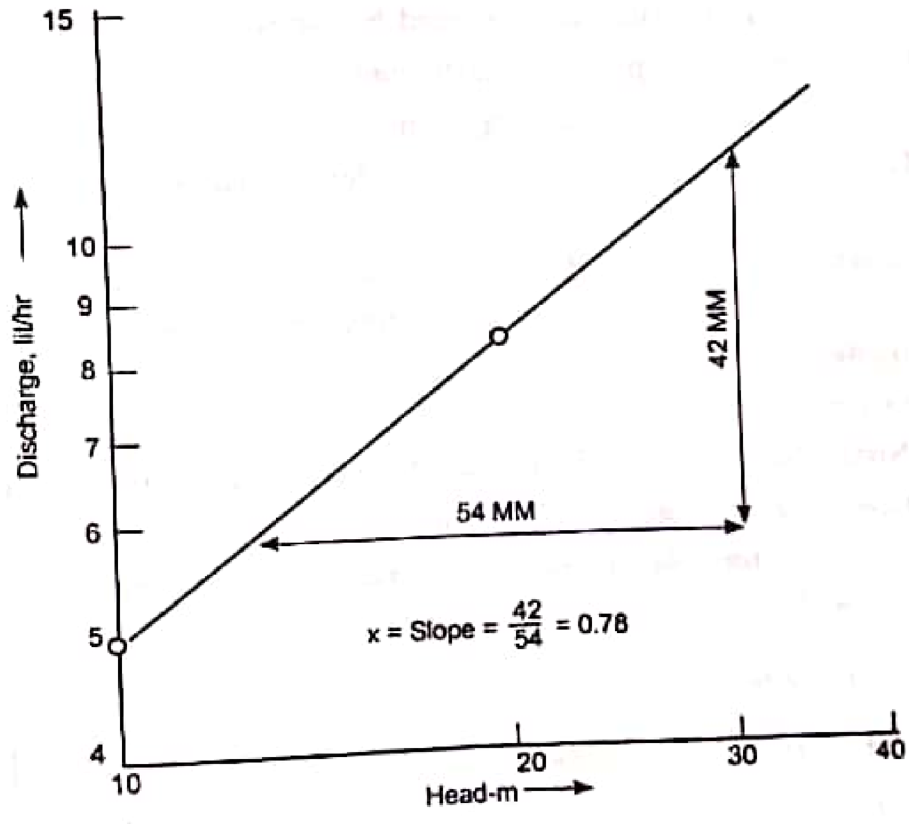

Fig. 4.1 Procedure for graphically determining the exponent 'x'

For sprinkler system, flow regime is always turbulent with $x = 0.5$, therefore eq. 4.4 can be written as,

$$q = K_d.H^{0.5}$$

$$q = K_d\sqrt{H} \quad ...4.10$$

The various values of operating pressure and discharge for different nozzle sizes between 2.4 and 5.6 mm and sprinkler pressure between 1.4 and 4.7 kg/cm² are given in the Table 4.1. The average value of K_d over the recommended range of operating pressure for each nozzle size with angle of trajectory between 22 and 28° is also given in the same table.

4.1.4 Water spread area of sprinkler

The irrigation area covered by a rotating head sprinkler may be estimated by using the formula suggested by Cavazza (Pillsbury, 1968),

$$A = \pi R^2 \quad ...4.11$$

in which, $R = 1{\cdot}35\sqrt{dh}$

where,

A = area covered by the sprinkler, m²

R = radius of wetted area covered by the sprinkler, m

D = diameter of sprinkler nozzle, mm

h = pressure head at the nozzle, m

Maximum area is covered when sprinkler jet makes an angle of 30 to 32° above horizontal.

Example 3. *Determine the water spread area of sprinkler having sprinkler nozzle diameter of 3.0 × 2.5 mm at a operating pressure of 2 kg/cm².*

Solution.

Given,

Nozzle having 3.0 × 2.5 mm diameter, that is maximum diameter= 3.0 mm

Operating pressure, h = 2 kg/cm² =20 m

Using the formula suggested by Cavazza, area covered by the sprinkler

$A = \pi R^2$

where, $R = 1{\cdot}35\sqrt{dh}$

$$R = 1{\cdot}35\sqrt{3 \times 20} = 10{\cdot}45 \text{ m}$$

$$A = \pi R^2 = 343.359 \text{ m}^2$$

$$= \pi \times (10{\cdot}45)^2$$

$$= 343 \text{ m}^2$$

∴ Water spread area of sprinkler nozzle = 343 m²

(**Note:** As the throw of water from large diameter nozzle will be on higher side, the same has been considered in calculation of radius and area.)

Table 4.1 Nozzle Discharges and Wetted Diameters for Typical 12.7 and 19.05 mm Bearing Impact Sprinklers With Trajectory Angles Between 22 And 28^0 and Standard Nozzles Without Vanes

Sprinkler pressure, m	Nozzle diameter, mm									
	2.4 mm		2.8 mm		3.2 mm		3.6 mm		4.0 mm	
	Nozzle discharge and wetted diameter									
	lit/s	M	Lit/s	m	Lit/s	M	lit/s	m	lit/s	m
14.06	0.071	19.20	0.097	22.25	0.141	23.16	0.182	24.07	0.222	24.99
17.58	0.080	19.51	0.109	23.16	0.155	23.47	0.199	24.38	0.243	25.91
21.09	0.088	19.81	0.119	23.47	0.169	23.77	0.214	24.68	0.262	26.51
24.61	0.095	20.12	0.129	23.47	0.181	24.07	0.229	24.99	0.280	26.82
28.12	0.102	20.42	0.138	23.77	0.192	24.38	0.242	25.29	0.297	27.12
31.64	0.108	20.73	0.146	24.07	0.203	24.69	0.252	25.60	0.314	27.43
35.15	0.113	21.03	0.154	24.38	0.214	24.99	0.268	25.90	0.329	27.73
38.67	0.118	21.34	0.162	24.38	0.223	25.29	0.278	25.90	0.343	28.04
42.18	0.124	21.64	0.170	24.69	0.232	25.60	0.293	26.51	0.360	28.34
45.70					0.240	25.60	0.304	26.82	0.373	28.65

(Contd..)

Table 4.1 *Contd..*

Sprinkler pressure, m	Nozzle diameter, mm							
	4.4 mm		4.8 mm		5.2 mm		5.6 mm	
	Nozzle discharge and wetted diameter							
	lit/s	M	Lit/s	m	Lit/s	M	lit/s	m
21.09	0.293	26.82	0.346	27.73	0.410	28.65	4.781	29.26
24.61	0.316	27.43	0.376	28.65	0.445	29.56	5.204	30.48
28.12	0.338	28.04	0.403	29.26	0.476	30.17	5.563	31.08
31.64	0.359	28.65	0.428	29.87	0.504	30.78	5.898	31.69
35.15	0.379	28.95	0.452	30.48	0.533	31.39	6.232	32.30
38.67	0.397	29.26	0.474	30.78	0.558	31.69	6.522	32.61
42.18	0.414	29.56	0.494	31.08	0.582	32.0	6.781	32.91
45.70	0.430	29.87	0.516	31.39	0.605	32.30	7.002	33.22
	0.447	30.17	0.535	31.69	0.627	32.61	7.191	33.52

(**Note:** Horizontal lines represent upper and lower recommended pressure boundaries).

Drop size is reduced as pressure increases or nozzle size decreases (Scheleusener and Kidder, 1960). Fig. 4.2 shows mean drop diameter increases as the distance from sprinkler increases. Drop size can also be reduced by using means other than high pressure to cause jet break, which is explained earlier.

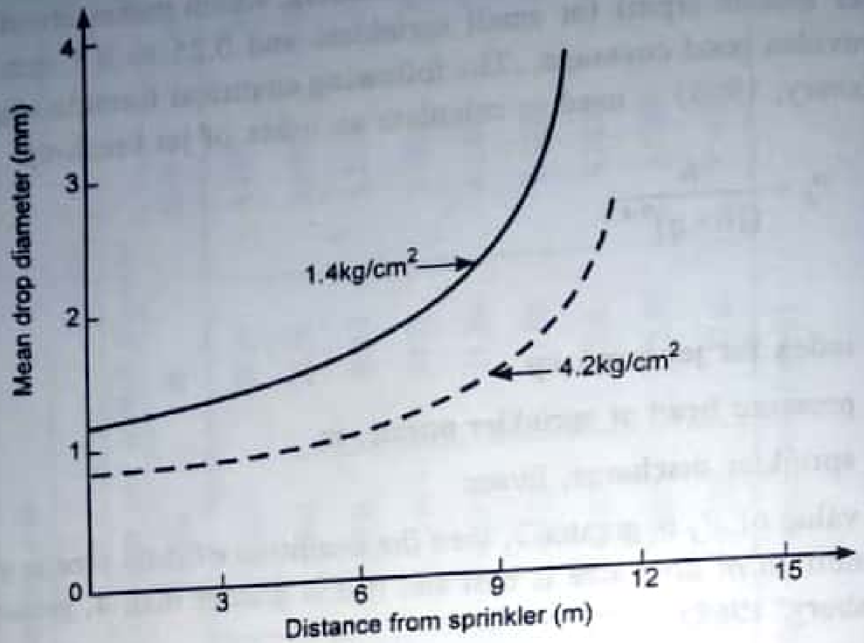

Fig. 4.2 Drop size at various distances from a standard 4 mm nozzle operating at different pressures

Table 4.2 Terminal Velocities and Kinetic Energies Associated With Different Size Raindrops

Drop diameter (mm)	*Drop volume (mm^3)*	*Terminal velocity (m/sec)*	*Kinetic energy, J/m^2*	
			In relation to 1 mm drop	*Per mm of rain*
0.5	0.07	1.8	0.03	1.6
1.0	0.5	3.8	1.0	7.3
1.5	1.8	5.3	6.5	14.1
2.0	4.2	6.5	22.8	20.8
2.5	8.2	7.3	57.0	26.6
3.0	14.2	7.9	115.7	31.1
3.5	22.5	8.4	205.0	34.8
4.0	33.5	8.7	332.0	37.6
4.5	47.8	8.9	499.0	39.8
5.0	65.5	9.1	707.5	41.2

Source: Keller and Bliesner (1990)

4.1.5 Index for jet brake-up

Brake-up of jet of water is necessary to obtain the uniformity of coverage and to minimize the droplet size. There is natural tendency of jets to break-up because of air resistance. Generally, break-up increases with pressure and by having slots in the nozzle. Slow rotation sprinklers, which makes about 0.67 to 1 revolution per minute (rpm) for small sprinklers and 0.25 to 0.5 rpm for large sprinklers provides good coverage. The following empirical formula suggested by Tanda (Phillsbury, 1968) is used to calculate an index of jet break-up.

$$P_d = \frac{h}{(10 \times q)^{0\cdot4}} \qquad \ldots 4.12$$

where,

P_d = index for jet break-up

h = pressure head at sprinkler nozzle, m

q = sprinkler discharge, lit/sec

If the value of P_d is greater 2, then the condition of drop size is good; if it is 4, then condition of drop size is best and if it is greater than 4, pressure being wasted (Pillsbury, 1968).

Example 4. *Determine the index for brake up of jet of water for a sprinkler having discharge of 0.40 m^3/hr at operating pressure of 2.0 kg/cm^2.*

Solution:

Given,

Sprinkler discharge, q =0.40 m^3/hr = 0.1 lit/sec

Operating pressure, h = 2.0 kg/cm^2 =20 m

By using the formula given by Tanda,

$$P_d = \frac{h}{(10 \times q)^{0\cdot4}} = \frac{20}{(10 \times 0\cdot1)^{0\cdot4}} = 4\cdot84$$

Drop impact tends to cause soil surface sealing and to reduce infiltration, especially on bare soils. The kinetic energy of falling drop is the product of one half of its mass and the square of its velocity. With sprinkler irrigation drop size typically ranges from 0.5 to 5.0 mm and have terminal falling velocities varying from 2 to 22 m/s, respectively. Table 4.2 shows terminal velocities and kinetic energies associated with different drop sizes.

4.1.6 Application rate of sprinkler

It is an extremely important parameter. The rate at which sprinkler apply water on the soil surface, when a group of them are operating close together is called the application rate. This is measured in mm/hr.

The application rate depends on,

i) The size of sprinkler nozzle

ii) Operating pressure of the system

iii) Spacing between the sprinklers

Increasing the nozzle size or pressure and bringing the sprinkler close together, will increase the application rate.

When sprinkler application rates are too high, then runoff and erosion can occur. The average rate of application, often called 'precipitation intensity' and is obtained by dividing the discharge of sprinkler by its spacing.

Application rate =

[Sprinkler discharge (lit/hr)] / [lateral spacing (m) × sprinkler spacing (m)]

$$I = \frac{q}{S_l \times S_m} \qquad ...4.13$$

where,

I = application rate, mm/hr

q = discharge of sprinkler, lit/hr

S_m = lateral spacing, along the main or submain, m

S_l = sprinkler spacing, along the lateral, m

Normally, sprinkler irrigation systems are designed, such that no runoff occurs. Thus, the rate at which a sprinkler system is designed to apply water is less than the infiltration capacity of the soil that is the maximum rate at which water can enter the soil at a given time.

The Fig. 4.3 gives the relationship between the infiltration capacities of the soil at two constant rate of application. Curve A shows that the infiltration capacity of typical soil is highest immediately after irrigation begins and then decreases steadily as time increases, is called basic infiltration rate. Generally in very deep and homogeneous soil the basic infiltration rate is equal to the saturated hydraulic conductivity of the soil. The horizontal line B shows the rate of application by sprinkler system and this should be less than the infiltration capacity of the soil. There is no possibility of runoff until the line B crosses line A and application rate exceeds infiltration capacity. The crossed area below the line B and above the line

A is the available runoff. The line C shows a system of application rate that never exceeds the infiltration capacity of soil. This type of application rate can be continued indefinitely without runoff. Therefore the sprinkler system may commonly be designed to apply the water at rate less than basic infiltration rate of soil.

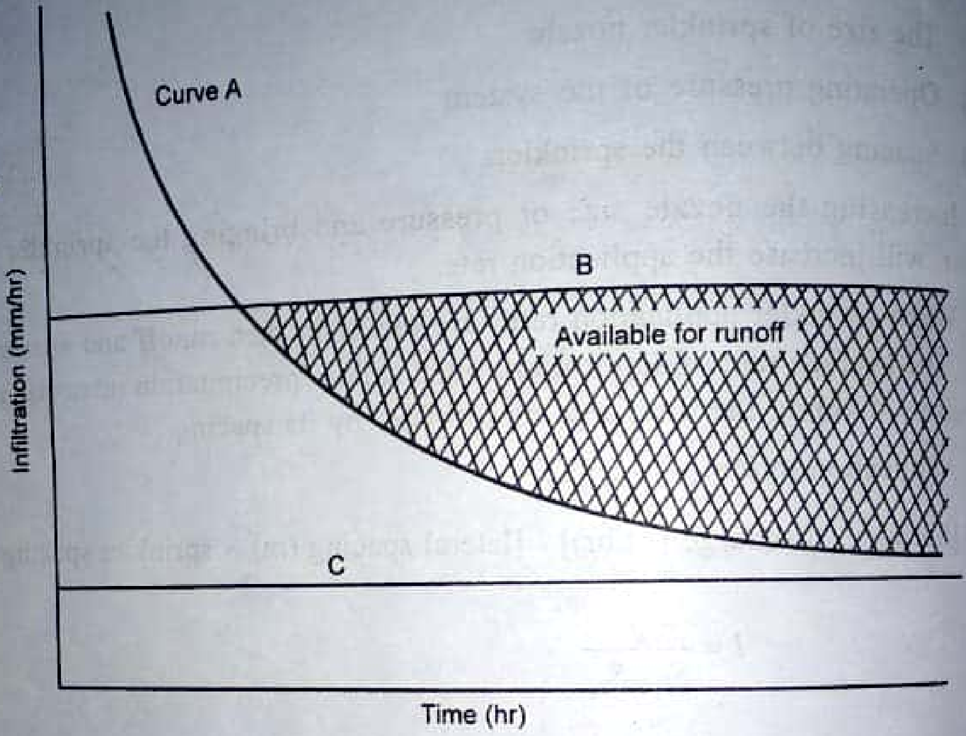

Fig. 4.3 Relationship between infiltration capacity of a soil and two constant application rates

Table 4.3 shows basic infiltration rates for different soil textures of bare soil with and without vegetative cover.

Table 4.3. Basic Infiltration Rate of Different Soil Textures

Soil	*Basic infiltration rate (mm/hr)*	
	Vegetative condition	*Non-vegetative condition*
Coarse sand	19 to 25	8.9
Fine sand	13 to 19	6.4
Fine sandy loam	8.9 to 13	5.1
Silty loam	6.4 to 10.2	3.8
Clay loam	2.5 to 7.6	2.5

Source: Pair *et. al.*, (1983).

Example 5. *Determine the application rate of sprinkler having discharge of 0.81 m^3/hr with sprinklers spaced at 12 m distance on lateral and lateral spaced at 12 m distance from each other.*

Solution:

Given,

Sprinkler discharge, $q = 0.81 \ m^3/hr = 810$ lit/hr

Sprinkler spacing = 12 m × 12 m

$$I = \frac{q}{S_l \times S_m} = \frac{810}{12 \times 12} = 5{\cdot}6 \text{ mm/hr.}$$

Example 6. *Compute the rate of application for 0.95 lit/sec sprinkler discharge, if the sprinkler spacing is 18 m × 12 m.*

Solution:

Given,

Sprinkler spacing = 18 m × 12 m

Sprinkler discharge, $q = 0{\cdot}95$ lit/sec

By using the formula for sprinkler application rate

$$q = \frac{S_1 \times S_m \times I}{3600} = \frac{12 \times 18 \times I}{3600}$$

$$0{\cdot}95 = \frac{12 \times 18 \times I}{3600}$$

$$I = 15{\cdot}83 \text{ mm/hr.}$$

4.2 Sprinkler Selection

Sprinkler selection is the process of choosing the sprinklers for the farm irrigation system. Sprinklers are normally selected on the basis of cost, operating pressure requirements and ability to provide designed daily irrigation requirements (DDIR) with acceptable uniformity without runoff. In addition to this, sprinklers must have proper nozzle angle (trajectory), droplet size, distance of throw and application pattern characteristics for particular crop, soil and wind conditions.

There are numerous types and makes of sprinklers available with different manufacturers. The actual selection is based largely upon design information furnished by the manufacturer. It is necessary to procure the information brochure of the sprinkler from the supplier. These brochures includes the information in respect of operating pressure, corresponding discharges, throw diameters and rate of application. The data given in the Table 4.4 may serve as a guideline in selecting pressure and desired spacing.

Table 4.4 Classification of Sprinklers and Their Adaptability

Type of sprinkler	*Very low pressure (0.35 to 1.00 kg/cm²)*	*Low pressure (1.00 to 2.10 kg/cm²)*	*Medium pressure (2.10 to 4.15 kg/cm²)*	*High pressure (3.5 to 6.9 kg/cm²)*	*Very high pressure (5.5 to 8.3 kg/cm²)*	*Undertree low angle (0.7 to 3.5 kg/cm²)*	*Perforated pipe (0.3 to 1.4 kg/cm²)*
General characteristics	Special thrust springs or reaction type arms	Usually single nozzle oscillating or long arm dual nozzle design	Either single or dual nozzle design	Either single or dual nozzle design	One large nozzle with smaller supplemental nozzles to fill in pattern gaps. Small nozzle rotates the sprinklers.	Designed to keep stream trajectories below fruit and foliage by lowering the nozzle angle	Portable irrigationpipe wit lines of small perforations in upper third of pipe perimeter
Range of wetted diameters	6 to 15	18 to 24 m	23 to 37 m	34 to 70 m	60 to 120 m	12 to 27 m	Rectangular 3 to 15 m wide
Recommended application rate	10 mm/hr	5 mm/hr	5 mm/hr	13 mm/hr	16 mm/hr	8 mm/hr	13 mm/hr
Droplet characteristics	Water drops are large due to low pressure	Water drops are fairly well broken	Water drops are well broken over entire wetted diameter	Water drops are well broken over entire wetted diameter	Water drops are extremely well broken	Water drops are extremely well broken	Water drops are large due to low pressure

Table 4.4 contd..

Type of sprinkler	*Very low pressure (0.35 to 1.00 kg/cm²)*	*Low pressure (1.00 to 2.10 kg/cm²)*	*Medium pressure (2.10 to 4.15 kg/cm²)*	*High pressure (3.5 to 6.9 kg/cm²)*	*Very high pressure (5.5 to 8.3 kg/cm²)*	*Undertree low angle (0.7 to 3.5 kg/cm²)*	*Perforated pipe (0.3 to 1.4 kg/cm²)*
Moisture distribution pattern	Fair	Fair to good at upper limits of pressure range	Very good	Good except where wind velocities exceed 6 km/hr	Acceptable in calm air. Severely distorted by wind.	Fairly good. Diamond pattern recommended are spaced shere laterals more than one tree inter space.	Good, pattern is rectangular
Adaptations and limitations	Small acreages confined to soils with intake rates exceeding 13 mm/hr and to good ground cover on medium to coarse textured soils.	Primarily for under tree sprinkling in orchards. Can be used for field crops and vegetables.	For all field crops and most irrigable soils. Well adapted to over tree sprinkling in orchards and groves and to tobacco shades	Same as for intermediate pressure sprinklers except where wind is excessive	Adaptable to close growing crops that provide a good ground cover. For rapid coverage and for odd-shaped areas. Limited to soils with high intake rates.	For all orchards or citrus groves. In orchards where wind will distort over tree sprinkler patterns. In orchards where available pressure is not sufficient for operation of over tree sprinklers.	For low growing crops only. Unsuitable to soils with relatively high intake rates. Best adapted to small acreages of high value crops. Low operating pressure permits use of gravity or municipal supply.

Sprinkler discharge and diameter of coverage for given sprinkler nozzle at different operating pressure are given in the Table 4.5.

Table 4.5 Sprinkler Discharge and Diameter of Spray at Different Operating Pressure

Nozzle size, mm	*Pressure of sprinkler, kg/cm²*	*Diameter of spray, m*	*Discharge*		*Application rate at various sprinkler spacing, mm/hr*	
			lit/sec	*lit/hr*	*12m×12m*	*13m×13m*
3.2	1.5	22	0.1389	500	3.47	2.95
	2.0	23	0.1583	570	3.95	3.37
	3.0	25	0.1944	700	4.86	4.14
	4.0	26	0.225	810	5.62	4.79
3.5	1.5	23	0.1611	580	4.02	3.43
	2.0	24	0.1833	660	4.58	3.90
	3.0	26	0.2250	810	5.62	4.79
	4.0	27	0.2583	930	6.45	5.50
4.0	1.5	23	0.2027	730	5.06	4.31
	2.0	25	0.2361	850	5.90	5.02
	3.0	27	0.2861	1030	7.15	6.09
	4.0	28	0.3277	1180	8.19	6.98

Each manufacture should recommend a combination of nozzle sizes and operating pressures to give best break up of stream and distribution pattern for uniform application. Generally, single nozzle sprinklers are recommended only for small nozzles with limited diameter of coverage or for part circle sprinklers. Because the distribution and coverage depends on the angle of the stream from the horizontal and the rate of application, sprinklers should be selected from manufacturer's table given in the Appendix 1-A to 3-B.

4.3 Sprinkler Spacing

The basic criteria used for the selection of spacing for any given sprinkler nozzle pressure and wind velocity combination is the uniformity of water distribution. To achieve uniform distribution of water, it is necessary to overlap the area of influence of the sprinklers. The overlapping area increases with the increase in wind velocity. Table 4.6 may be used as a guideline in the design of sprinkler under different wind conditions.

Table 4.6 Recommended Sprinkler Spacing Under Windy Conditions

Sr. No.	*Wind velocity, km/hr*	*Maximum spacing*	
		Square spacing	*Triangular spacing*
1.	0 to 4.8	55 % of diameter	60 % of diameter
2.	4.8 to 9.6	50 % of diameter	55 % of diameter
3.	9.6 to 19.2	45 % of diameter	50 % of diameter
4.	Above 19.2	40 % of diameter	45 % of diameter

In general a coefficient of uniformity (U_c) of at least 85 per cent is recommended for delicate and shallow rooted crops, such as potatoes and most other vegetables. A U_c between 75 and 83 per cent is generally adequate for deep-rooted field crops, such as alfalfa, corn, cotton and sugar beets. Tree and vine crops have deep spreading roots system and can be adequately irrigated if the U_c. is above 70 per cent. However, when applying chemicals through the system a U_c above 80 per cent is recommended. Where, systems have low U_c due to wind, then chemicals should be applied only during no wind conditions.

4.4 Design of Sprinkler Laterals

Lateral conveys water from mainline or sub main to the individual sprinkler. A lateral has equally spaced sprinklers along its length. Laterals should be laid across prominent slopes to minimize the variation of pressure along the lateral and it is not possible to have same pressure at each outlet. Lateral should be located at right angle to the prevailing wind direction, whenever possible. As the water flows along the lateral in the beginning the flow will be equal to the combined discharge of all the sprinklers and its volume decreases along the length because of discharge through the sprinkler. However, it is not convenient to design the lateral for a tapering section. A uniform diameter of lateral is adopted. The total flow rate entering the lateral is calculated and a trial diameter of pipe is selected, which then needs to be checked for frictional losses.

The American Society of Agricultural Engineering (1978) recommended that the total pressure variation in the lateral practically should not be more than 10 per cent of the design lateral pressure. Thus, if the design lateral pressure is 4 kg/cm^2, the pressure at any sprinkler along a lateral should not be less than 3.55 kg/cm^2 or greater than 4.34 kg/cm^2.

If the lateral runs uphill or downhill, allowance for this difference in elevation should be made in determining the variation in head. If the water runs uphill, less pressure will be available at nozzle; if it runs downhill there will be a tendency to balance the loss of head due to friction (Fig. 4.4).

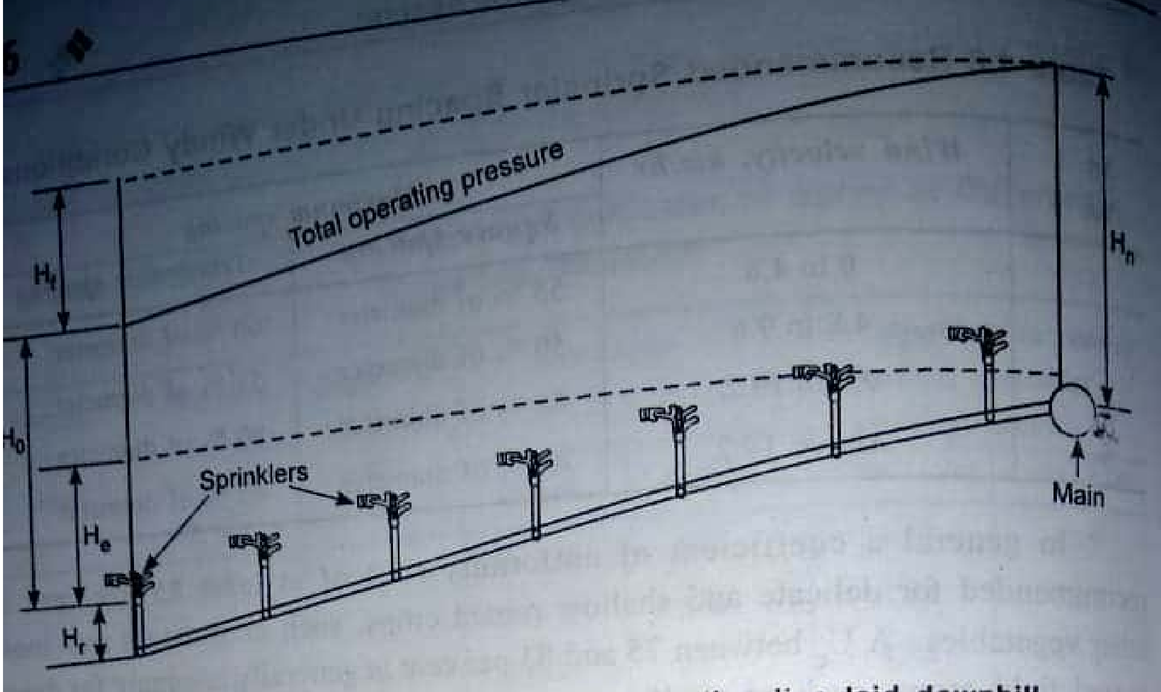

Fig. 4.4 Pressure profile in sprinkler irrigation line laid downhill.

Assuming that, the flow is constant throughout the length without sprinkler, the frictional head loss in the lateral is calculated by using different equations.

1. Scobey's equation:

Scobey (1930) gave an equation for friction or head loss in sprinkler lateral, which is expressed as,

$$\Delta H = 4{\cdot}10 \times 10^6 \times K_s \times Q^{1{\cdot}9} \times D_1^{-4{\cdot}9} \times L_1 \times F \quad \ldots 4.14$$

where,

ΔH = total friction loss in lateral, m

K_s = Scobey's coefficient for retardation

L_1 = length of lateral pipe, m

Q = total discharge, lit/sec

D_1 = inside diameter of lateral, mm

F = correction factor, based on number of sprinklers on one lateral

Suggested values of F are given in the Table 4.7. Recommended values of Ks for design purposes are 0.32 for new transit pipe, 0.40 for steel pipe or portable aluminum pipe with couplers and 0.42 for portable galvanized steel pipe with couplers.

The size of lateral is selected so that the friction loss (ΔH) is within allowable limits adjusted for elevation difference along the line. The selected lateral diameter should be the closest nominal size available commercially. The standard tables based on Scobey's formula are available and can be used for the purpose.

Table 4.7 Correction Factor 'F' For Friction Losses In Aluminum Pipes With Multiple Outlets (Scobey exponent, m-1.9)

No. of sprinklers	*Correction factor, F*	
	1st sprinkler, one sprinkler interval from main[a]	*1st sprinkler, one half sprinkler interval from main[b]*
1	1.00	1.00
2	0.63	0.51
4	0.48	0.41
6	0.43	0.38
8	0.41	0.37
12	0.39	0.36
16	0.38	0.36
20	0.37	0.35
30 or more	0.36	0.35

'a' adapted from Christiansen (1948)
'b' adapted from Jensen and Frantini (1957)

2. The Hazen-Williams equation:

This is the most commonly used equation for estimating the frictional loss in sprinkler laterals of various pipe materials and is given by,

$$J = \frac{\Delta H_1 \times 100}{L} = K \times \left(\frac{Q}{C}\right)^{1.852} \times D_1^{-4.871} \times F \qquad \ldots 4.15$$

where,

J = head loss gradient, m/100 m

ΔH_1 = the total friction loss in lateral, m

L = the length of lateral pipe, m

K = conversion constant, equal to 1.212×10^{12} for metric units

Q = the total discharge, lit/sec

C = the friction coefficient which depends on pipe material as given in the Table 4.8, dimensionless

D_1 = the inside diameter of lateral, mm

F = outlet factor, depends on number of outlets (sprinklers) on one lateral

The values of outlet factor, F are given in Appendix- 4 and 5.

Equation (4.15) can also be written as

$$\Delta H_1 = \frac{J \times L \times F}{100} = K \times \left(\frac{Q}{C}\right)^{1.852} \times D_1^{-4.871}$$

or

$$\Delta H_1 = K \times \left(\frac{Q}{C}\right)^{1.852} \times D_1^{-4.871} \times \frac{L}{100} \times F \quad ...4.16$$

Table 4.8 Values of C For Use in the Hazen-Williams Equation

Sr. No.	Pipe material	C
1.	Plastic (PVC)	150
2.	Epoxy coated steel	145
3.	Cement asbestos	140
4.	Galvanized steel	135
5.	Aluminum (with couplers)	130
6.	Steel (new)	130
7.	Steel (15 years old) or concrete	100

The Hazen-Williams equation was developed from study of water distribution systems that used 75 mm or larger diameter pipes and discharges greater than 3.2 lit/sec. Under these flow conditions, the Reynolds number is greater than 5×10^4 and the formula computes friction loss satisfactorily. However, for small diameter smooth walled pipe used in the sprinkler system, the Hazen-Williams equation with a C=150, under estimate the frictional losses. Hence for simplicity a simple equation developed by Watters and Keller (1978) for use with smooth plastic pipes less than 125 mm in diameter can be used and is given by,

$$J = \frac{\Delta H \times 100}{L} = K \times Q^{1.75} \times D_1^{-4.75} \times F \quad \text{(for small pipe)} \quad ...4.17$$

where,

K is conversion constant, 7.89×10^7 for metric units

For larger plastic pipe, where the diameter is greater than 125 mm, the frictional head loss gradient can be calculated approximately by,

$$J = \frac{\Delta H \times 100}{L} = K \times Q^{1.83} \times D_i^{-4.83} \times F \quad \text{(for large pipe)} \qquad ...4.18$$

where,

K is conversion constant, 9.58×10^7 for metric units

These formulae are easy to use than the Hazen-Williams equation and more accurately predict friction loss for 21°C water temperature flowing in smooth plastic pipe.

The design capacity of sprinklers on a lateral with uniform spacing should be based on the average operating pressure. Where the frictional loss in the laterals is within 20 per cent of average pressure, the average head for design in a sprinkler lateral line can be expressed approximately by (Fig. 4.5).

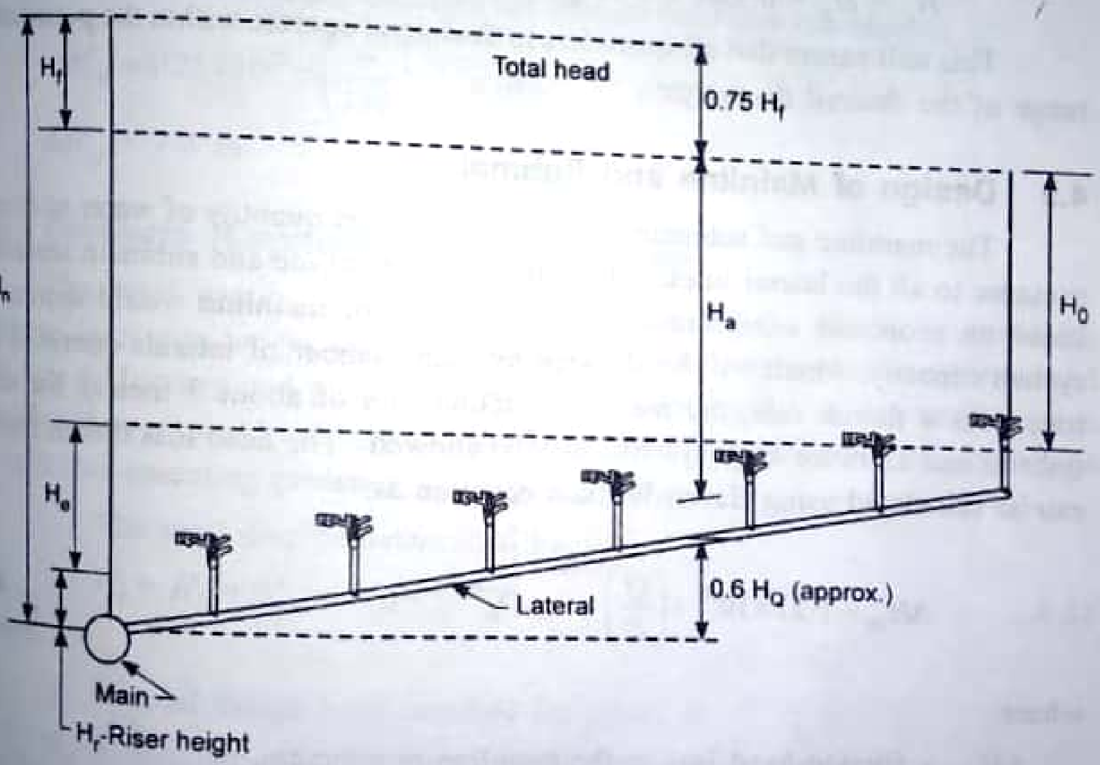

Fig. 4.5 Pressure profile in a sprinkler lateral laid uphill.

$$H_a = H_o + 0.25\ \Delta H + 0.4\ H_e \qquad ...4.19$$

where,

H_a = average pressure at the nozzle, m

H_o = nozzle pressure at the farthest end of line, m

ΔH = friction head loss in the lateral, m

H_e = maximum difference in elevation between the junction with the main and the farthest sprinkler on the lateral, m

Making the allowances for the difference in elevation along the lateral and for riser height, head at the mainline due to lateral can be expressed as,

$$H_n = H_o + \Delta H \pm H_e + H_r \qquad \text{...4.20}$$

where,

H_n = head at the main line, m

H_r = riser height, m

'H_e' is positive for uphill and negative for downhill from equation 4.20, H_o can be written as,

$$H_o = H_a - 0.25\Delta H - 0{\cdot}4H_e \qquad \text{...4.21}$$

Substituting this value of H_o in equation 4.20,

$$H_n = H_a + 0{\cdot}75H \pm 0{\cdot}6H_e + H_r \qquad \text{...4.22}$$

This will ensure that all sprinklers in the lateral operate within the permissible range of the desired discharge.

4.5 Design of Mainline and Submain

The mainline and submain conveys the required quantity of water at desired pressure to all the lateral lines. The selection of mainline and submain should be based on economic consideration. The diameter of mainline would depend on system capacity, which will be decided by total number of laterals operated at a time. As a thumb rule, the mainline friction loss of about 3 meters for small systems and 12 m for large systems may be allowed. The head loss due to friction can be calculated using Hazen-William equation as,

$$\Delta H_m = 1{\cdot}21 \times 10^{10} \times \left(\frac{Q}{C}\right)^{1{\cdot}852} \times D_m^{-4{\cdot}871} \times L \qquad \text{...4.23}$$

where,

ΔH_m = friction head loss in the mainline or submain, m

Q = discharge of pipe, lit/sec

C = friction coefficient, depends on pipe material, dimensionless

D_m = internal diameter of pipe, mm

L = length of pipe, m

Example 7. *Calculate the frictional head loss through mainline using following data:*

i) Diameter of main pipe = 110 mm

ii) Rate of discharge flowing through mainline = 8 lit/sec

iii) Length of pipe = 1000 m

iv) Hazen-William constant = 150 (for PVC)

Solution:

Given,

Q = 8 lit/sec

C = 150

D = inside pipe diameter = 110 – 4·6 = 105·4 mm

(Assuming thickness of pipe as 2·3 mm).

L = 1000 m

Using Hazen-William equation for friction head loss calculation,

$$\Delta H_m = 1{\cdot}21 \times 10^{10} \times \left(\frac{8}{150}\right)^{1{\cdot}852} \times 105{\cdot}4^{-4{\cdot}871} \times 1000$$

$$\Delta H_m = 7{\cdot}4 \text{ m}$$

4.6 Pressure Requirement of the System

The total pressure of the system depends on the sprinkler operating pressure, riser pipe height, head loss due to friction in main and submain and head loss due to fixtures and pumping water level. The head loss due to fixtures is considered as a local head loss and should be approximately equal to 10 per cent of sprinkler operating pressure.

The total may be determined by,

$$H_t = H_n + H_m + H_j + H_s \qquad \ldots 4.24$$

where,

H_t = total design head required for pump, m

H_n = maximum head required at the mainline to operate the sprinklers on lateral at required average pressure, m

H_m = maximum friction loss in the mainline, m

H_j = elevation difference between the pump and the junction of the lateral and the main, m

H_s = elevation difference between the pump and the water supply after drawdown, m

4.7 Capacity of the Sprinkler System

When the rate of application and spacing of sprinkler have been determined then the required sprinkler capacity can be computed by the formula,

$$Q = q \times N_s \qquad \text{...4.25}$$

where,

Q – discharge of all sprinklers, lit/sec

q – discharge of each sprinkler, lit/sec

N_s – total number of sprinklers operating at a time

The discharge of each sprinkler depends upon sprinkler spacing and the water application rate and can be computed as,

$$q = \frac{S_l \times S_m \times I}{3600} \qquad \text{...4.26}$$

where,

q = discharge of individual sprinkler, lit/sec

S_l = sprinkler spacing along the lateral, m

S_m = lateral spacing along the main, m

I = the optimum application rate, mm/hr

The required system capacity (pump capacity) may also be calculated by the formula,

$$Q = 2780 \times \frac{A \times d}{F \times H \times E} \qquad \text{...4.27}$$

where,

Q = discharge capacity of the pump, lit/sec

A = area to be irrigated, ha.

d = net depth of water application, cm

F = number of days allowed for the completion of one irrigation

H = number of actual operating hours, hrs/day

E = water application efficiency, per cent

4.8 Layouts of Sprinkler System

Different field layouts of sprinkler system for main and lateral for fully portable, semi portable and portable main and lateral are shown in Fig. 4.6

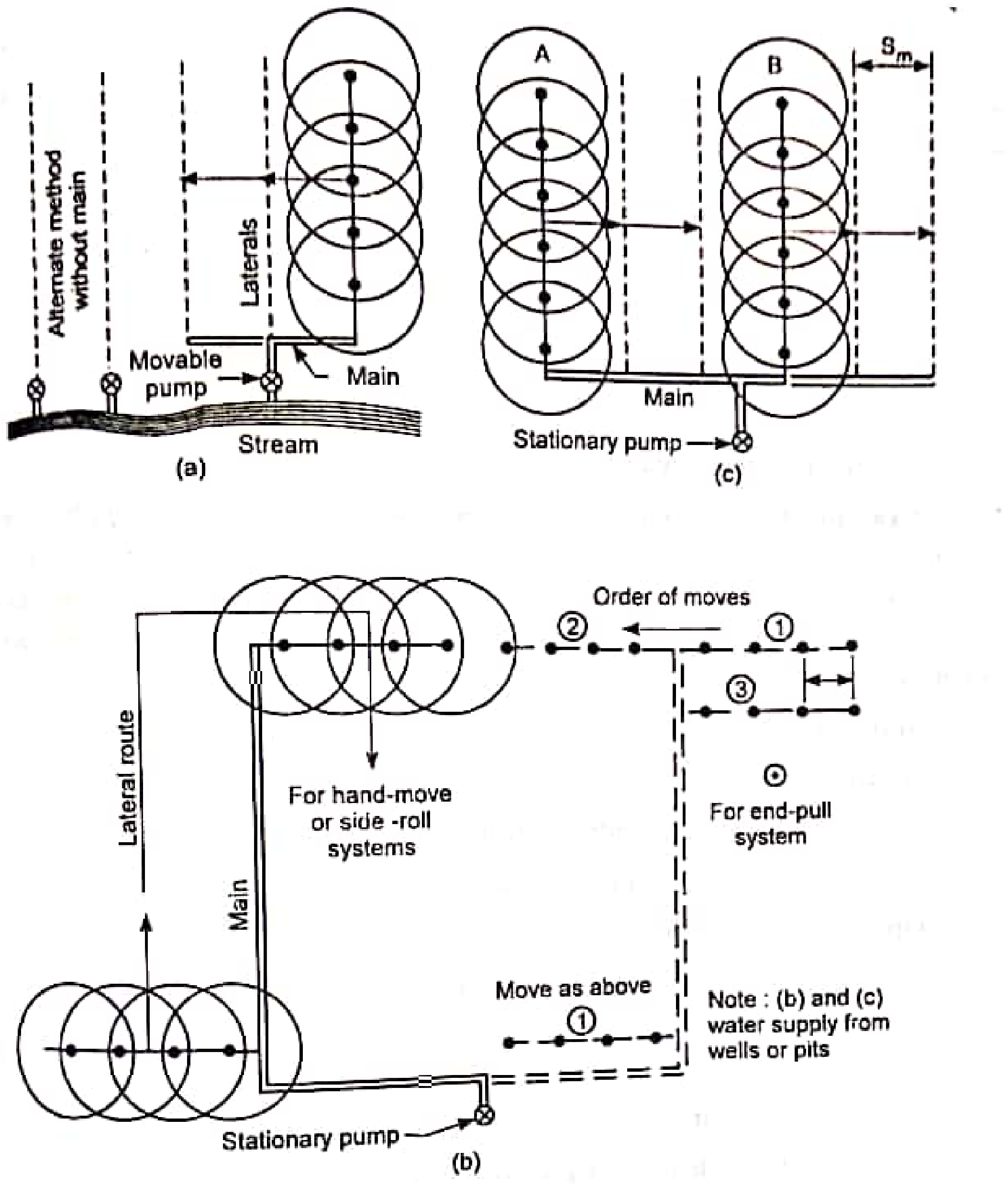

Fig. 4.6 Different field layouts of sprinkler system for main and lateral (a) Fully portable, (b) Semi portable, (c) Portable main and lateral

Example 8. *Determine the discharge of individual sprinkler to apply the water at the rate of 10 mm/hr having spacing when the sprinkler spacing is 12m and lateral spacing is 12 m.*

Solution

Given,

$S_l = 12\text{m},\ S_m = 12\text{m},\ I = 10\text{mm/hr}$

$$q = \frac{S_l \times S_m \times I}{3600} = \frac{12 \times 12 \times 10}{3600} = 0.4 \text{ lit/sec}$$

Example 9. *Determine the required capacity of a sprinkle system to apply water at a rate of 12 mm/hr. Two lateral lines of 9 m length having 8 sprinklers at a distance of 12 m are placed. Spacing between two laterals is 12 m.*

Solution

Given,

$$N_s=16,\ S_l=12\text{ m},\ S_m=12\text{m},\ I=12\text{ mm/hr}$$

$$q=\frac{S_l\times S_m\times I}{3600}=\frac{12\times12\times12}{3600}=0{\cdot}48\text{ lit/sec}$$

$$\text{Total system capacity}=q\times N_s=0{\cdot}48\times16=7{\cdot}6\text{ lit/sec}$$

Example 10. *Determine the time of irrigation required to apply 5 cm of irrigation water to a 10 ha. of land at the rate of 12 mm/hr. Two lateral lines of 108 m long are spaced at 12 m apart. Nine sprinklers are spaced at 12 m interval on each lateral line. Calculate the system capacity and number of days required to complete one irrigation assuming 8 operating hrs per day.*

Solution

Given,

Area =10 ha, depth of irrigation = 5cm,

$N_s=9$, $S_l=12$m, $S_m=12$ m, $I=12$mm/hr

Operating hrs = 8 hrs/day

(*i*) Irrigation time to apply 5 cm irrigation water @12 mm/hr

= 50/12 = 4·16 hr

Time required for shifting the lateral is 1 hr

Total time per irrigation = 4·16 + 1 = 5·16 hrs.

(*ii*) Area of the field = 5 ha = 50,000 m^2

Length of field = $\sqrt{50{,}000}$ = 224 m

The entire length of 224 m will be covered by two lateral lines of 108 m

Total number of moves required = 224/12 = 18.6 says 19 moves

Total time of irrigation required = 19 × 5·16 = 98 hrs.

Total days required for irrigation = 98/8 = 12·25 days

(*iii*) System capacity

$$Q=2780\times\frac{10\times5}{12\times8\times70}=20.68\text{ lit/sec}$$

Example 11. *Calculate the frictional loss 'H_f' in lateral of sprinkler irrigation system, using following data* *i) Length of lateral = 96 m*

ii) Diameter of lateral = 63 mm

iii) Spacing between sprinklers on lateral = 12 m

iv) Discharge of individual sprinkler = 0·26 lit/sec

v) The first sprinkler is spaced 12 m from the submain (K_s = 0·32)

vi) Number of sprinkler = 8

vii) Outlet factor, F = 0·415

Solution:

Total discharge of all sprinklers,

$$Q = 0{\cdot}26 \times 8 = 2{\cdot}08 \text{ lit/sec}$$

$$C = 150 \text{ for PVC pipes, } L = 96 \text{ m}, F = 0{\cdot}415,$$

For 63 mm PVC pipe, inner diameter = 59 mm

Method I: By using Hazen-William equation

$$\Delta H = 1{\cdot}21 \times 10^{10} \times \left(\frac{Q}{C}\right)^{1{\cdot}852} \times D^{-4{\cdot}871} \times L \times F$$

$$\Delta H = 1{\cdot}21 \times 10^{10} \times \left(\frac{2{\cdot}08}{150}\right)^{1{\cdot}852} \times 59^{-4{\cdot}871} \times 96 \times 0{\cdot}415$$

$$\Delta H = 0.41\text{m}$$

Method II: By using Scobey's formula,(K_s= 0.32)

$$\Delta H = 4{\cdot}10 \times 10^6 \times K_s \times Q^{1{\cdot}9} \times D^{-4{\cdot}9} \times L \times F$$

$$\Delta H = 4{\cdot}10 \times 10^6 \times 0{\cdot}32 \times 2{\cdot}08^{19} \times 59^{-4{\cdot}9} \times 96 \times 0{\cdot}415$$

$$\Delta H = 0{\cdot}44 \text{ m}$$

4.9 Selection of Pump

Irrigation pumps are costly installation. A major part of energy is used in agriculture pumping. In selecting pump for particular job the relationship between head and capacity at different speeds should be known along with well as pump efficiency. The curves that provide these data are called characteristics curves as shown in Fig.4.7. The head capacity curve shows the total head developed by the pump for different rates of discharges. At zero flow, the head developed is known as set of head. A pump should be selected such that it will have high efficiency for wide range of discharge (Fig. 4.8). The characteristics curve can be obtained from pump manufacturer. These curves will vary in shape and magnitude depending on size of the pump, type of impeller and over all design.

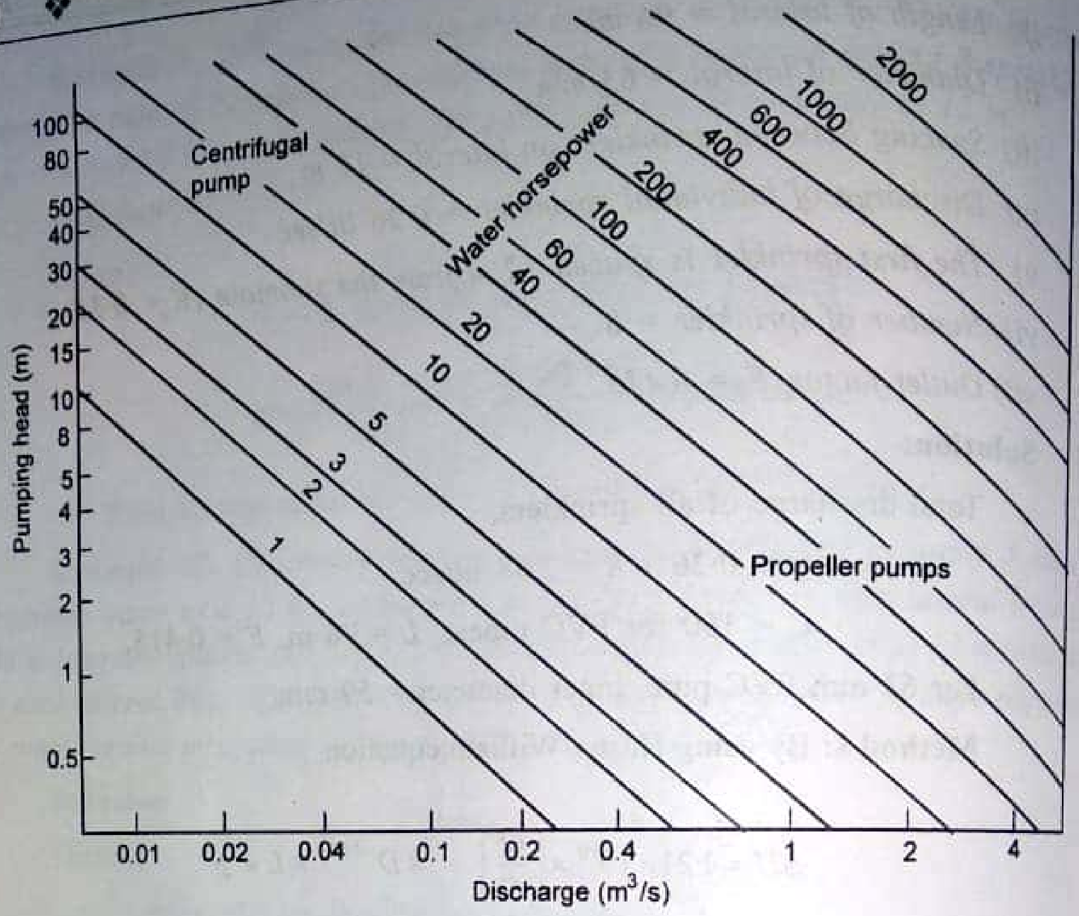

Fig. 4.7 Pump selection chart by discharge and head

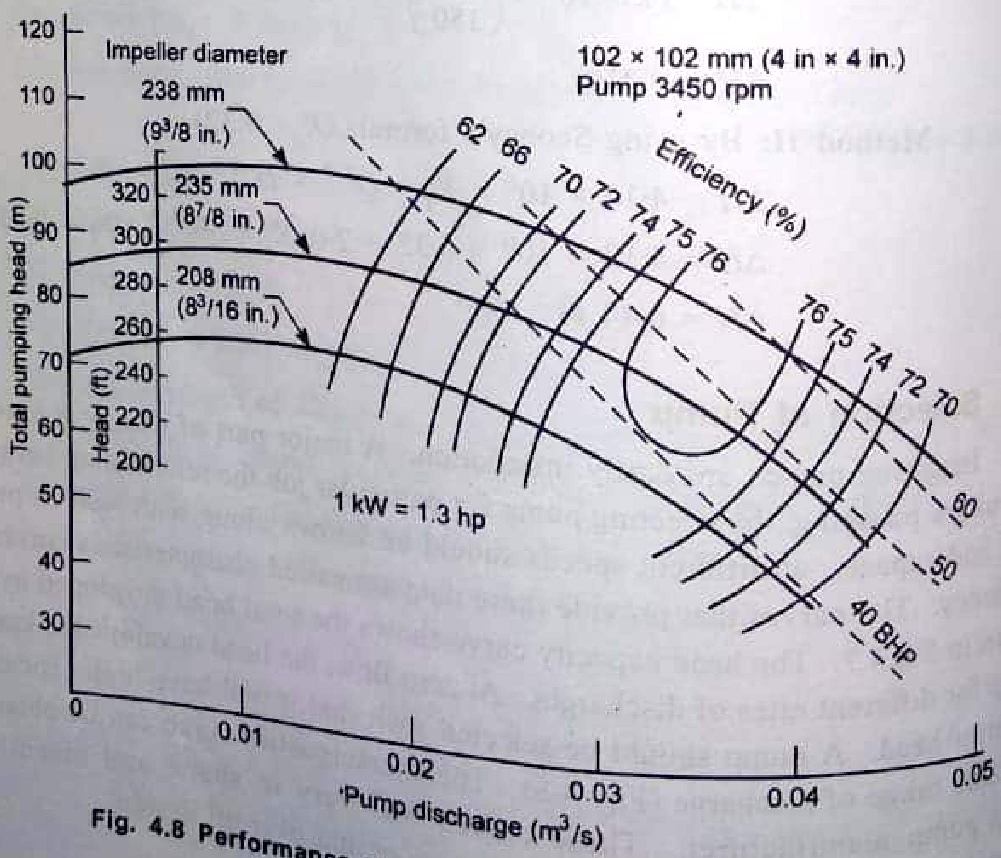

Fig. 4.8 Performance characteristics of a centrifugal pump.

The pump required for sprinkler system should be of high head and low discharge characteristics because the sprinklers usually require high pressure. In order to select the pump of appropriate size, it is highly essential to collect the pump information with respect to pump characteristics of possible makes. The pump should be selected in such a way that the required operating pressure will be available at the sprinklers and it should lift the designed discharge from the source of water.

Total head of the pump is also known as the total dynamic head and can be calculated as,

Total head of pump = suction head + delivery head + operating pressure of sprinkler +filter loss + mainline friction loss + fitting loss +elevation difference

where,

Operating pressure of sprinkler is about 25 m (2.5 kg/cm^2)

Filter losses are assumed to be 2 m for sand filter and 2 m for screen/disc filter

Fitting losses are assumed as 2 m

Approximately,

$$H.P. = \frac{Q \times H_n}{75 \times E_p} \qquad \text{...4.28}$$

where,

Q = maximum flow rate of the system or pump capacity, lit/sec

H_n = total dynamic head, m

E_p = pump efficiency

$H.P.$ = the horse power

4.10 General Rules for Sprinkler System Design and Layout

Sprinkler irrigation system as technical based system, some general rules may be helpful for design and layout of hand-move or mechanical move system other than center pivot. The spacing between sprinklers on lateral and lateral spacing along the main should be optimum for the given soil and crop, subject to availability of water and power in that region, *e.g.* greater spacing require higher pressures and thus higher pumping costs, these wide or greater spacing are more easily justified where the power costs are low. Greater spacing also requires a higher application rate in which case the infiltration rate may be the limiting factor.

The following general rules for layout should be kept in mind:

1. Layout should be modified to apply different rates and amount of water in case of spatial variability in soil properties.
2. In the layout, main should be laid along the general direction of steepest slope
3. Whereas laterals should be laid across the slope or nearly on the contour
4. In telescopic lateral design, lateral pipe sizes should be limited to not more than two diameters
5. Layout should facilitate and minimize lateral movement during the season
6. Difference in the number of sprinklers operating on the various set-ups should be minimum
7. Booster pump should be considered where small portions of the field would require a high pressure of the pump
8. In case of field channels running along one edge of the farm, a portable pumping set and sprinkler unit with the lateral extending to the field may be used to draw water directly from the channel and distribute it through sprinklers.
9. Any system in which the laterals are moved should be planned for successive irrigations in strict rotation, as that the interval between irrigations is the same for each portion of a field
10. The well may be located at a high corner or more likely at the center of the farm to minimize the distance the water must be pumped
11. In abstract, the arrangement selected should provide for a minimal investment in irrigation pipe, have a low labor requirement and provide for an application of water over the total area in the required period of time.

Example 12. *Determine the size of sprinkler nozzle, diameter of lateral and main line and size of pump required using following data.*

i) Length of lateral = 84 m

ii) Distance between laterals along the main = 18 m

iii) Length of main = 72 m

iv) Application rate = 12 mm/hr

v) Maximum head required at the main to operate sprinkler (H_n) = 30 m

vi) Elevation difference between pump and junction of lateral (H_j) = 2 m

vii) *Maximum elevation difference between main and last sprinkler on the lateral* $(H_e) = 2{\cdot}2$ *m, on up hill slope*

viii) *Elevation difference between pump and water supply after draw down = 3·5 m*

ix) *Scobey's coefficient,* $K_s = 0{\cdot}32$

Assume, pressure variation in lateral = 20 per cent

Coefficient of discharge $(C_d) = 0{\cdot}96$

Assume Sprinkler spacing as 12 m

Solution:

Given, $S_l = 12$ m, $S_m = 18$ m, $I = 12$ mm/hr, $H_n = 30$ m

$H_j = 2$ m, $H_e = 2{\cdot}2$ m, $H_s = 3{\cdot}5$ m, $\Delta H_f = 20$ %

Step 1- Required discharge of individual sprinkler

$$q = \frac{S_1 \times S_m \times I}{3600} = \frac{12 \times 18 \times 12}{3600} = 0{\cdot}72 \text{ lit/sec}$$

Step 2- Determination of nozzle size,

$C_d = 0.96$, $H = 30$ m, g = 9·8 m/sec^2

By using orifice flow formula,

$$q = C_d\, a \sqrt{2gh}$$

$$a = \frac{q}{C_d \sqrt{2gh}} = \frac{0{\cdot}72 \times 10^{-3}}{0{\cdot}96\sqrt{2 \times 9{\cdot}8 \times 30}} = 0{\cdot}00003092 \text{ m}^2$$

$$d = 0{\cdot}00627\text{m} = 6{\cdot}27 \text{ mm}$$

By referring Appendix-2A, it is seen that the largest single nozzle of 6 mm (at 3 kg/cm^2 operating pressure) or twin nozzle of 6·0 mm × 2·5 mm having sprinkler discharge of 2·65 m^3/hr can be selected.

Step 3- Discharge of lateral (Q_l)

No. of sprinkler on lateral =

lateral length/sprinkler spacing = $\frac{84}{12}$ = 7 Nos.

Discharge of lateral = sprinkler discharge × no. of sprinklers = 0·72 × 7 = 5·04 lit/sec

Step 4- Design of lateral, select HDPE lateral of 63 mm diameter *i.e.* inside diameter $D = 58{\cdot}6$ mm

Outlet factor for 7 sprinklers, $F = 0.425$ (From Appendix-4).

Total allowable variation of pressure in lateral = 20% of 30 m = 6m

Using Scobey's formula, $K_s = 0{\cdot}32$

$$\Delta H = 4{\cdot}10 \times 10^6 \times K_s \times Q^{1{\cdot}9} \times D^{-4{\cdot}9} \times L \times F$$

$$\Delta H = 4{\cdot}10 \times 10^6 \times 0{\cdot}32 \times 5{\cdot}04^{1{\cdot}9} \times 58{\cdot}6^{-4{\cdot}9} \times 84 \times 0{\cdot}425$$

$$\Delta H = 2{\cdot}20 \text{ m}$$

As the frictional head loss is less than 6m, hence the pipe of 63mm outer diameter can be selected as lateral.

Select lateral of 63 mm outer diameter

Step 5- Design of main, select HDPE main of 63 mm diameter *i.e.* inside diameter, $D = 58{\cdot}6$ mm

Length of main (l_m) = 72 m

Discharge of main = 5·04 lit/sec

(*Note:* As the discharge in case of overhead sprinkler is large, it is always advisable to operate one lateral at a time. By doing this pump size can be reduced.)

Using Scobey's formula, $K_s = 0{\cdot}32$

$$\Delta H = K_s \times L \times Q^{1{\cdot}9} \times D^{-4{\cdot}9} \times 4{\cdot}10 \times 10^6$$

$$\Delta H = 0{\cdot}32 \times 72 \times 5{\cdot}04^{1{\cdot}9} \times 58{\cdot}6^{-4{\cdot}9} \times 4{\cdot}10 \times 10^6$$

$$\Delta H = 4{\cdot}43 \text{ m}$$

Allowable variation of pressure due to friction = 6 – 2·20 = 3·80 m

As calculated head loss for main is more than allowable head loss, 63 mm diameter main is not suitable, hence select higher diameter pipe size.

Head loss for 75 mm diameter of HDPE main at 5·04 lit/sec discharge is 1.78 m

Select main of 75 mm outer diameter

Step 6-Selection of pump

Total head of pump,

$$H_t = H_n + H_m + H_j + H_s$$

where,

$$H_n = H_a + 0{\cdot}75\ \Delta H_l \pm 0{\cdot}6\ H_e + H_r$$

where,

H_r is riser height (1·0 m), H_e = (+)2·2 m, ΔH_1 = 2·20 m

By substituting the values in the above formula,

H_n = 34·85 m

$H_t = H_n + H_m + H_j + H_s$

H_t = 34·85 +1·78 +2 +3·5 = 42·13 m

Total dynamic head, H_t is 42·13 m and discharge, Q is 5·04 lit/sec

By taking pump efficiency, E_p as 60 per cent

$$H.P. = \frac{Q \times H}{75 \times E_p} = \frac{5 \cdot 04 \times 42 \cdot 13}{75 \times 0 \cdot 6} = 4 \cdot 7 \text{ say 5 H.P.}$$

Example 13. *Design a sprinkler irrigation system for a square 10 ha. field to irrigate the entire field within a 4 day period. Not more than 12 hrs per day are available for moving the pipe and sprinkler unit. Depth of application is to be 50 mm at each setting at a rate not to exceed 11 mm/hr. A well 25 m deep located at the center of the field will provide the following draw down-discharge characteristics obtained from a well test,*

12 m – 12·6 lit/sec

15 m – 15·8 lit/sec

20 m – 18·9 lit/sec

Design for an average pressure of 2·80 kg/cm² at the nozzle. Highest point in the field is 1·3 m above the well site and 1 m risers are needed on the sprinklers. Assuming a pump efficiency of 60 per cent and assuming that the engine will furnish 70 per cent of its rated output for continuous operation, determine the rated output for a water cooled internal combustion engine.

Solution:

Given,

i) Square field of 10 ha, *i.e.* having 316·23 m side length

ii) Total irrigation time 4 days

iii) Irrigation time in a day is 12 hrs

iv) Depth of irrigation is 50 mm

v) Average pressure at nozzle is 280 Kpa

vi) Static head is 25 m

Design of lateral

Discharge of lateral =

discharge of one sprinkler × no. of sprinkler on one lateral

$= 0{\cdot}22 \times 11 = 2{\cdot}42$ lit/sec

Select lateral of 50 mm outer diameter HDPE pipe. inside $\phi = 44.7$

Using Scobey's formula, $K_s = 0{\cdot}32$

$$\Delta H = 4{\cdot}10 \times 10^6 \times K_s \times Q^{1\cdot9} \times D^{-4\cdot9} \times L \times F$$

$$\Delta H = 4{\cdot}10 \times 10^6 \times 0{\cdot}32 \times 2{\cdot}42^{1\cdot9} \times 44{\cdot}7^{-4\cdot9} \times 66 \times 0{\cdot}392$$

$$\Delta H = 1{\cdot}49 \text{ m}$$

As allowable head loss is less than 20 per cent of the required available head (28 m), the selected lateral of 50 mm outer diameter can be accepted.

Design of submain

Select submain of 75 mm outer diameter HDPE pipe, inner diameter = 70.8 mm

Using Scobey's formula, $K_s = 0{\cdot}32$

$$\Delta H = 4{\cdot}10 \times 10^6 \times K_s \times Q^{1\cdot9} \times D^{-4\cdot9} \times L \times F$$

$$\Delta H = 4{\cdot}10 \times 10^6 \times 0{\cdot}32 \times 12{\cdot}1^{1\cdot9} \times 70{\cdot}8^{-4\cdot9} \times 60 \times 0{\cdot}451$$

$$\Delta H = 3{\cdot}48 \text{ m}$$

Design of main

Select main of 90 mm outer diameter HDPE pipe, inner diameter = 85·8 mm

Using Scobey's formula, $K_s = 0{\cdot}32$

$$\Delta H = 4{\cdot}10 \times 10^6 \times K_s \times Q^{1\cdot9} \times D^{-4\cdot9} \times L$$

$$\Delta H = 4{\cdot}10 \times 10^6 \times 0{\cdot}32 \times 12{\cdot}1^{1\cdot9} \times 85{\cdot}8^{-4\cdot9} \times 60$$

$$\Delta H = 3{\cdot}01 \text{ m}$$

Total head loss

$$H_t = H_n + H_l + H_m + H_e + H_o + H_r$$

$$H_t = 28 + 3{\cdot}48 + 3{\cdot}01 + 1{\cdot}3 + 25 + 1 = 61{\cdot}86 \approx 62 \text{ m}$$

Selection of pump

Select the pump that will deliver 12·1 lit/sec at the head of 64 m

$$H.P. = \frac{12{\cdot}1 \times 62}{75 \times 0{\cdot}60 \times 0{\cdot}70} = 23{\cdot}81 \approx 25 \text{ H.P.}$$

vii) Elevation difference in the field is 1·3 m

viii) Riser height is 1 m

$$\text{Irrigation time} = \frac{\text{depth of irrigation}}{\text{application rate}} + \text{system movement time}$$

$$= \left(\frac{50}{11}\right) + 1{\cdot}5 = 6{\cdot}04 \text{ i.e. } 6 \text{ hrs.}$$

Thus 2 moves per day are possible.

Since the area of 2 ha is to be irrigated in 4 days, area to be covered per day,

$$= \left(\frac{2}{4}\right) = 0{\cdot}5 \text{ ha} = 5000 \text{ m}^2$$

Field dimension are 71 m × 71 m

Select 12 m × 6 m ($S_m \times S_l$) spacing for sprinkler

$$\text{No. of lateral/set} = \frac{71}{12} = 5{\cdot}91 \text{ say } 5$$

$$\text{No. of sprinkler/lateral} = \frac{71}{6} = 11{\cdot}83 \text{ say } 11$$

Total no. of sprinklers = 11 × 5 = 55 nos.

Discharge of sprinklers,

$$q = \frac{S_l \times S_m \times I}{3600} = \frac{12 \times 6 \times 11}{3600} = 0{\cdot}22 \text{ lit/sec}$$

Total discharge = 0·22 × 55 =12·1 lit/sec

Size of nozzle

$$q = C_d \sqrt{2gh}$$

$$a = \frac{q}{C_d\sqrt{2gh}} = \frac{0{\cdot}22 \times 10^{-3}}{0{\cdot}95\sqrt{2 \times 9{\cdot}8 \times 28}} = 0{\cdot}00000988 \text{ m}^2$$

$$d = 0{\cdot}003548 \text{ m} = 3{\cdot}548 \text{ mm}$$

Select nozzle of 3·5 mm diameter

4.11 Model Design of Sprinkler Irrigation System

Example 14. *A 10 ha field is to be irrigated at a maximum rate of 11 mm/hr with a sprinkler system. The root zone is 0.8 m deep and the available moisture capacity of the soil is 90 mm/m depth of soil. The water application efficiency is 70 per cent and the soil is to be irrigated when 40 per cent of the available moisture capacity is depleted. The peak rate of moisture use is 5 mm/day. Determine the net depth of application per irrigation and depth of water to be pumped, days to cover the field and area to be irrigated per day.*

Solution:

Given

i) Area of field is 10 ha.

ii) Irrigation rate of 11 mm/hr

iii) Root zone depth is 0.8 m

iv) Available moisture holding capacity 90 mm/m

v) Water application efficiency is 70 per cent

vi) Peak rate of moisture use is 5 mm/day

Available moisture =

Available moisture capacity × root zone depth = 90 × 0·8 = 72 mm

Net depth of irrigation

= Available moisture × allowed moisture deficit

$$= 72 \times \left(\frac{40}{100}\right) = 28{\cdot}8 \text{ mm}$$

Gross depth of irrigation

= net depth of irrigation/ water application efficiency

$$= \left(\frac{28{\cdot}8}{0{\cdot}70}\right) = 41{\cdot}14 \text{ mm}$$

Irrigation period = Net depth/Peak rate of moisture use

$$= \frac{28{\cdot}8}{5} = 5{\cdot}76 \text{ say 6 days}$$

To cover the field in 6 days, the system must be able to pump,

= (Gross depth × Area to be irrigated)/Irrigation period

= (4·114 × 10)/6 = 6·856 ha-cm/day

The pump capacity, assuming operation period of 12 hrs. per day

$$Q = 2780 \times \frac{A \times d}{F \times H \times E} = 2780 \times \frac{10 \times 2 \cdot 88}{6 \times 12 \times 70} = 15 \cdot 88 \text{ lit/sec}$$

Area irrigated per day = Total area/Irrigation period = $\frac{10}{6} = 1 \cdot 66$ ha/day

Example 15. *Design a sprinkler irrigation system for a field having 4 ha area, with 100 per cent cropping intensity in kharif and rabi and 50 per cent in summer with 2 ha. area each for sorghum and pearl millet crop in kharif, 2 ha each for wheat and sunflower in rabi and 2 ha. of groundnut in summer. The peak water use rate was 5 mm/day for kharif, while 4 mm/day and 7 mm/day for rabi and summer, respectively. Soil type is sandy loam having water holding capacity of 190 mm/m and basic infiltration rate of 12.0 mm/hr. The effective root zone depth is 50 cm and the management allowable deficit is 50 per cent. Source of water is a well in one corner of the field having electric supply availability for 12 hr. a day for 6 days a week. Assume field irrigation efficiency of 80 per cent.*

Solution:

Given,

i) Area of field is 4 ha.

ii) Irrigation rate of 8.5 mm/hr

iii) Root zone depth is 0.50 m

iv) Water holding capacity is 190 mm/m

v) Management allowable deficit (MAD) is 50 per cent

vi) Peak water use

Kharif 5 mm/day

Rabi 4 mm/day

Summer 7 mm/day

v)

Crop	*Kharif*	*Rabi*	*Summer*
Sorghum	2	-	-
Pearl millet	2	-	-
Wheat	-	2	-
Sunflower	-	2	-
Ground nut	-	-	2

Step 1- Net irrigation depth =

(MAD × water holding capacity × root zone depth)/100

= (50 × 190 × 0·50)/100 = 47·50 mm

Step 2- Irrigation interval,

During *kharif*, $\frac{47 \cdot 50}{5} = 9 \cdot 5$ *i.e.* 10 days

Net irrigation interval = 10 − 1 = 9 days

During *rabi*, $\frac{47 \cdot 50}{4} = 11 \cdot 87$ *i.e* 12 days

Net irrigation interval = 12 − 1 = 11 days

During *summer*, $\frac{47 \cdot 50}{7} = 6 \cdot 78$ *i.e.* 7 days

Net irrigation interval = 7 − 1 = 6 days

Step 3- Area to be irrigated per day

During *kharif*, $\frac{4}{9} = 0.44$ ha

During *rabi*, $\frac{4}{11} = 0 \cdot 36$ ha

During *summer*, $\frac{2}{6} = 0 \cdot 33$ ha

Step 4- Gross demand per day

During *kharif*, $\frac{5}{0 \cdot 8} = 6 \cdot 25$ mm/day

During *rabi*, $\frac{4}{0 \cdot 8} = 5$ mm/day

During *summer*, $\frac{7}{0 \cdot 8} = 8 \cdot 75$ mm/day

Step 5- Volume of water required per irrigation (m^3) =

Area to be irrigated /day × gross depth × irrigation interval

During *kharif*, $0 \cdot 44 \times 10^4 \times 6 \cdot 25 \times 10^{-3} \times 9 = 24 \cdot 5$ m^3

During *rabi*, $0 \cdot 36 \times 10^4 \times 5 \times 10^{-3} \times 11 = 198$ m^3

During *summer*, $0 \cdot 33 \times 10^4 \times 8 \cdot 75 \times 10^{-3} \times 6 = 173 \cdot 25$ m^3

Step 6- System discharge required (m^3/hr) considering pumping for 12 hr per day

During *kharif*, $\frac{247 \cdot 5}{12} = 20 \cdot 62\ m^3/hr = 5 \cdot 77$ lit/sec

During *rabi*, $\frac{198}{12} = 16 \cdot 5\ m^3/hr = 4 \cdot 62$ lit/sec

During *summer*, $\frac{173 \cdot 25}{12} = 14 \cdot 44\ m^3/hr = 4 \cdot 04$ lit/sec

From Appendix-2A, select medium capacity heavy-duty sprinkler having twin nozzle of 5·0 × 2·5 mm size and of 0·44 lit/sec with 12 m x12 m spacing resulting in 11 mm/hr application rate which is less than basic infiltration rate of the soil.

Step 7- Rechecking the operating time required during peak demand indifferent seasons,

Operation time required (hr)

$$= \text{gross depth (mm / day)} \times \frac{\text{irrigation interval (days)}}{\text{rate of precipitation (mm / hr)}}$$

During *kharif*, $\frac{(6 \cdot 25 \times 9)}{11} = 5 \cdot 11$ hr.

During *rabi*, $\frac{(5 \times 11)}{11} = 5$ hr.

During *summer*, $\frac{(8 \cdot 75 \times 6)}{11} = 4 \cdot 77$ hr.

As the availability of power is for 12 hr. a day for 6 days, the irrigation can be effected easily.

Step 8- No. of sprinklers per day

= Area irrigated per day/Spacing of sprinklers

During *kharif*, $\frac{0 \cdot 44 \times 10^4}{12 \times 12}$, 30·55 say 31

During *rabi*, $\frac{0.36\times10^4}{12\times12} = 25$

During *summer*, $\frac{0.33\times10^4}{12\times12} = 22.92$ say 23

Step 9- Design discharge required of lateral =

No. of sprinklers × Discharge of one sprinkler

During *kharif*, 31× 0·44 = 13·64 lit/sec

During *rabi*, 25 × 0·44 = 11·00 lit/sec

During *summer*, 23 × 0·44 = 10·12 lit/sec

Step 10- No.of laterals operated day

$$= \frac{\text{Total no. of sprinklers operated per day}}{\text{No. of sprinklers on one lateral}}$$

During *kharif*, $\frac{31}{8} = 3.87 \approx 4$ nos.

During *rabi*, $\frac{25}{8} = 3.12 \approx 3$ nos.

During *summer*, $\frac{23}{8} = 2.87 \approx 3$ nos.

Considering lateral length of 96 m, 8 sprinklers will be placed at 12 m distance on each lateral.

Design of lateral

Length of lateral = 96 m

No. of sprinklers on one lateral = 8

Discharge of one lateral = 8 × 0·44 = 3·52 lit/sec

Operating pressure = 3 kg/cm^2 =30 m

Assume, height of riser = 1 m

Select HDPE lateral of 63 mm outer diameter, hence the inner diameter becomes 58.8 mm

Using Scobey's formula, $K_s = 0.32$

$\Delta H = 4.10 \times 10^6 \times K_s \times Q^{1.9} \times L \times F$

$\Delta H = 4.10 \times 10^6 \times 0.32 \times 3.52^{1.9} \times 58.8^{-4.9} \times 96 \times 0.41$

($F = 0.41$ for 8 sprinklers from the Appendix-4)

$\Delta H = 1.20$ m

which is less than 10 per cent of pressure head, hence can be accepted. Select 63 mm outer diameter HDPE lateral.

Design of submain (manifold)

The critical condition is during *kharif*, when 4 laterals are operating at a time

Discharge of manifold = 4 × 3·52 = 14·08 lit/sec

Length of manifold = 48 m

Select 75 mm outer diameter HDPE pipe as manifold

Using Scobey's formula, $K_s = 0{\cdot}32$

$$\Delta H = 4{\cdot}10 \times 10^6 \times K_s \times Q^{1{\cdot}9} \times D^{-4{\cdot}9} \times L \times F$$

$$\Delta H = 4{\cdot}10 \times 10^6 \times 0{\cdot}32 \times 14{\cdot}08^{1{\cdot}9} \times 70{\cdot}8^{-4{\cdot}9} \times 48 \times 0{\cdot}48$$

(F = 0·48 for 4 sprinklers from the Appendix-4)

$$\Delta H = 0{\cdot}70 \text{ m}$$

As this head loss is less than 10 per cent of operating head available, select the manifold of 75 mm diameter.

As the total head loss through lateral and submain are 20 per cent of 30 m, it can be accepted.

Design of main

Select 75 mm outer diameter HDPE pipe having 70·8 mm inner diameter as main

Using Scobey's formula, $K_s = 0{\cdot}32$

$$\Delta H = 4{\cdot}10 \times 10^6 \times K_s \times Q^{1{\cdot}9} \times D^{-4{\cdot}9} \times L$$

$$\Delta H = 4{\cdot}10 \times 10^6 \times 0{\cdot}32 \times 14{\cdot}08^{1{\cdot}9} \times 70{\cdot}8^{-4{\cdot}9} \times 48$$

$$\Delta H = 1{\cdot}47 \text{ m}$$

Total head loss

$$H_t = H_n + H_l + H_m + H_e + H_o + H_r$$

$$H_t = 28 + 1{\cdot}47 + 0{\cdot}70 + 1{\cdot}3 + 20 + 1 = 52{\cdot}47 \approx 52 \text{ m}$$

(Assume H_o as 20 m)

Selection of pump

Select the pump that will deliver 14·08 lit/sec at the head of 52 m

$$H.P. = \frac{14{\cdot}08 \times 52}{75 \times 0{\cdot}60 \times 0{\cdot}70} = 23{\cdot}24 \approx 25 \text{H.P.}$$

The detail layout of the system has been given in Fig. 4.9.

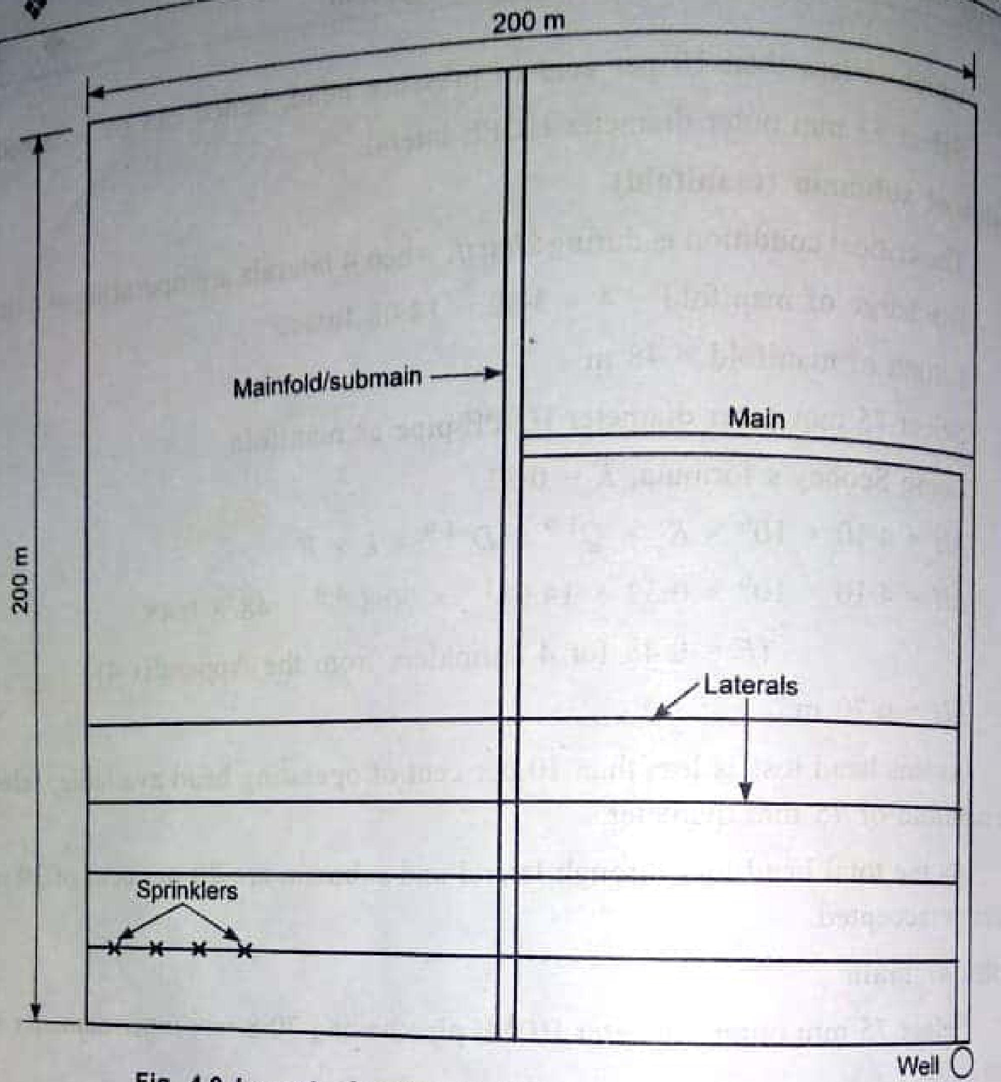

Fig. 4.9 Layout of sprinkler system as per design

EXERCISES

1. What are the principles involved in hydraulic design of sprinklers? Explain in brief.
2. What is meant by application rate of sprinklers? Explain the factors affecting it.
3. What are the general rules for sprinkler system design and layout?
4. What are the steps involved in the design of sprinkler irrigation system?

PROBLEMS

1. Determine the theoretical discharge of sprinkler nozzle of size 4·6 × 3·2 mm at a operating pressure of 2·0 kg/cm^2.
2. Determine the application rate of sprinkler having discharge of 1·02 m^3/hr for sprinklers spaced at 18 m on lateral, while lateral spaced at 12 m distance from each other.