Design of Sprinkler Irrigation System

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Sprinkler Irrigation Systems

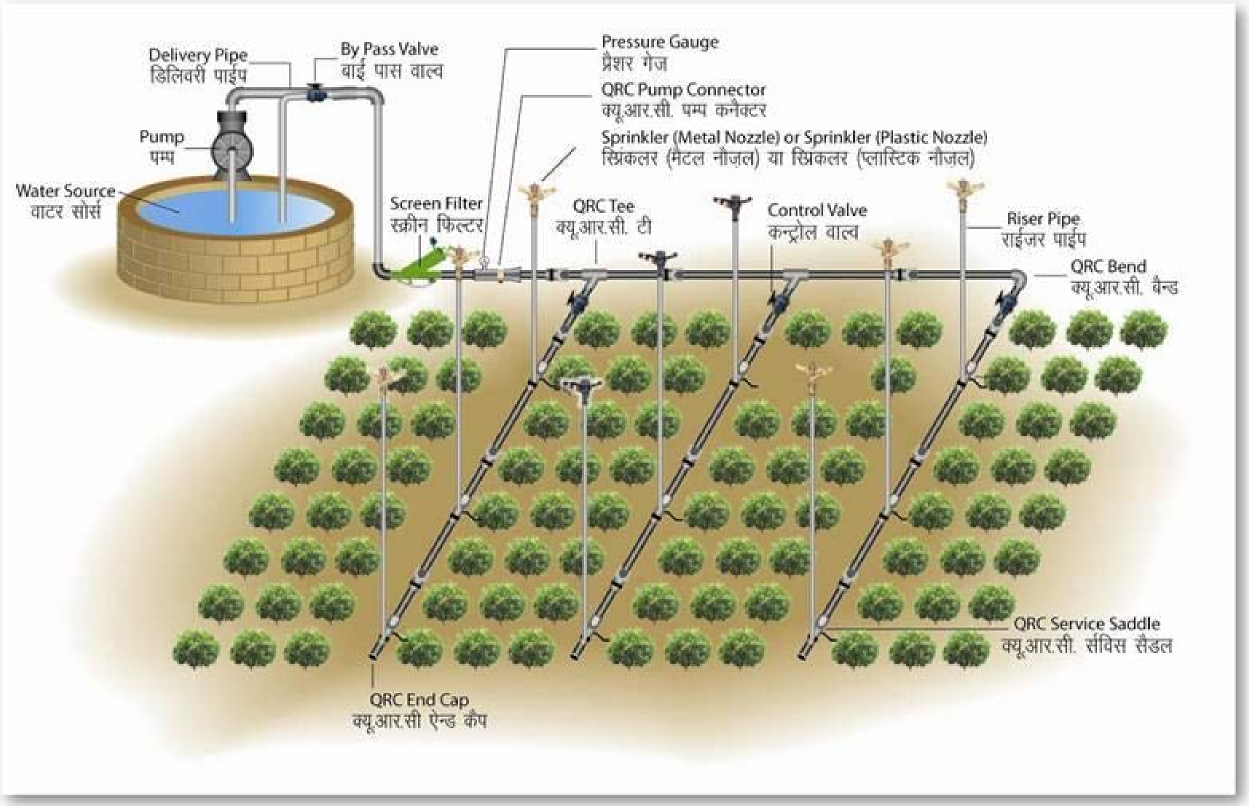
Basic Concept:-

- <u>Water is delivered through a pressurized pipe network to sprinklers, nozzles, or jets which spray the water into the air, to fall to the soil as an artificial "rain".</u>

- Sprinkler irrigation system can be defined as a "pressurized system, where water is distributed through a network of pipe lines to and in the field and applied through selected sprinkler heads or water applicators".

The basic components of a sprinkler system

- ➢ Water source
- ➢ Pump
- ➢ Filters
- ➢ Pipe network
- ➢ Sprinklers and
- ➢ Valves
- ➢ Flow meters and pressure gauges



Layout of Sprinkler Irrigation System (छिड़काव सिंचाई प्रणाली का रेखाचित्र)

Inventory of the Land and Water Resources

- **Topographical map of the Area**
  - Field boundaries and the locations of the bunds, farm roads building and location of water resources, cultivation of crops, contours, etc
- **Water Resources**
  - Information on quantity and quality of available water resources
- **Crops to be Irrigated**
  - Information on crops, its root zone depth, crop coefficient, and allowable depletion level
- **Climate**
  - Weather parameters such as pan evaporation, rainfall, temperature, relative humidity, wind speed and sunshine hours
- **Soils**
  - Field capacity, wilting point, bulk density and infiltration rate
- **Availability of Power Source**
  - Type of source of power can be electricity or diesel or both

Types of Sprinkler Systems Layout

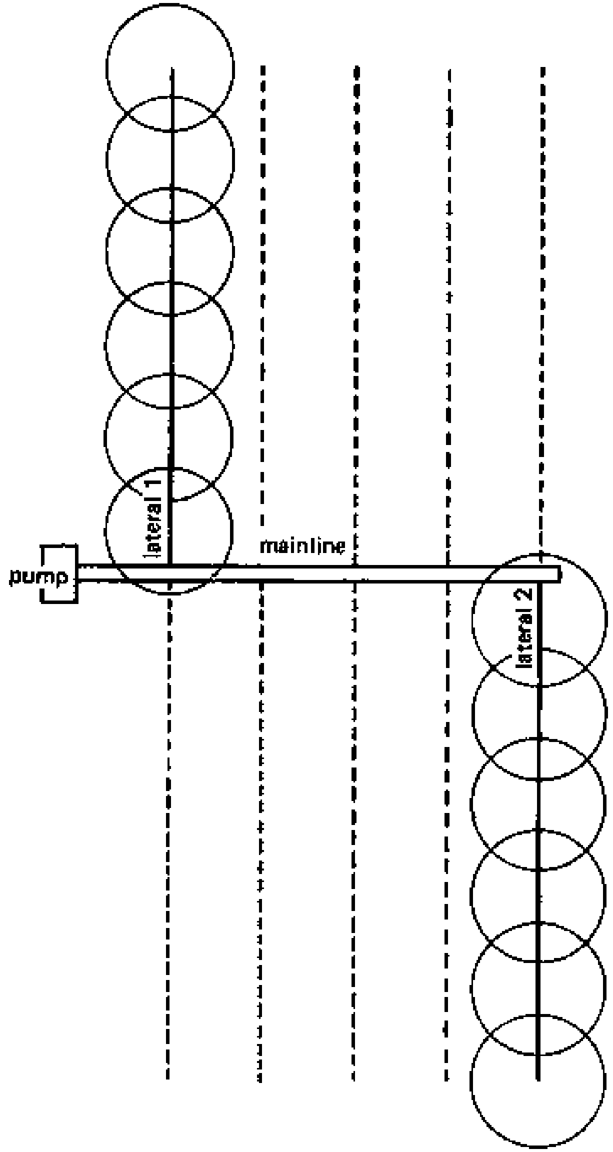


Figure: Hand-moved sprinkler system using two laterals (Laterals 1 and 2 in position 1)

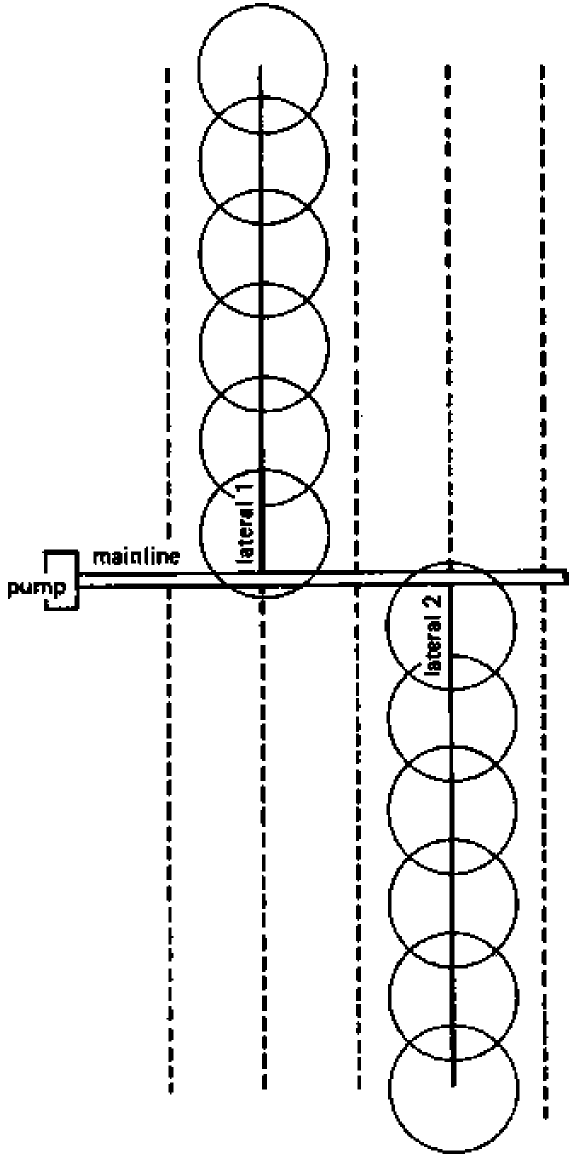


Figure: Hand-moved sprinkler system using two laterals (Laterals 1 and 2 in position 2)

Sprinkler Spacing:

The uniformity of water distribution from sprinklers depends on

- ✓ the operating pressure,
- ✓ wind velocity,
- ✓ rotation of sprinklers,
- ✓ spacing between sprinklers and laterals.

To obtain the greater uniformity

- ✓ Greater depth of water accumulate near sprinkler head and depth decreases gradually with distance from the sprinklers.
- ✓ That requires overlapping of spray pattern of sprinklers
- ✓ The spacing of sprinklers on laterals and the laterals spacing are adjusted.

Overlapping of sprinkler spacing for different wind speeds

Sl.No.	Average wind speed	Spacing
1.	No wind	65% of the water spread area of a sprinkler
2.	0-6 km/h	60% of the water spread area of a sprinkler
3.	6.5 to 13 km/h	50% of the water spread area of a sprinkler
4.	Above 13 km/h	30% of the water spread area of a sprinkler

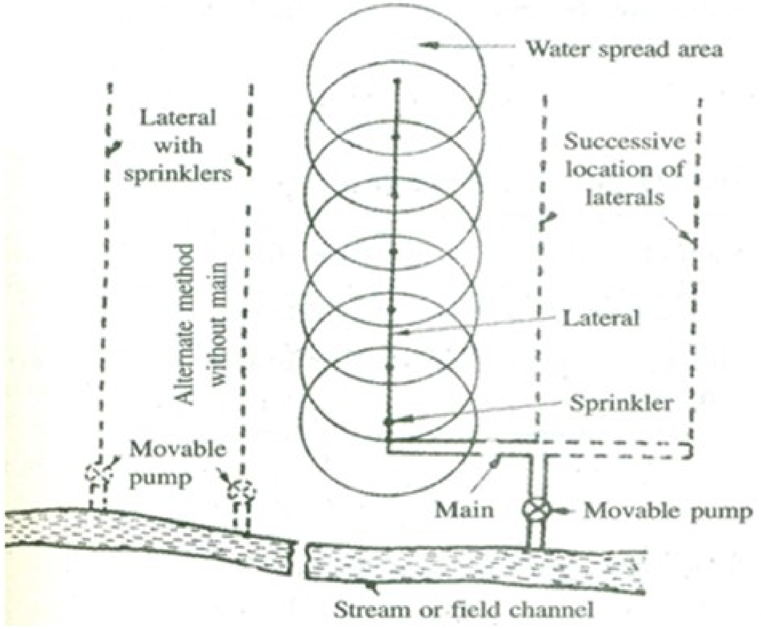


Fig. Typical field layouts for fully portable sprinkler units drawing water from streams or field channels. (Source: Michael, 2010)

Sprinkler System Design Parameters

Sprinkler Discharge Considering Area of Coverage:

The required discharge of an individual sprinkler is a function of the water application rate and the two-way spacing of the sprinklers.

$$q = \frac{s_l \times s_m \times I}{360} \qquad (1)$$

in which,

q = required discharge of individual sprinkler, litres/second

S_l = spacing of sprinklers along the laterals, m

S_m= spacing of laterals along the main, m

I = optimum application rate, cm/hr

Capacity of sprinkler system:

- The capacity of a sprinkler system is an important design parameter.
- It depends upon the total area to be irrigated, gross depth of water applied in each irrigation, and the net operation time allowed to apply water to this depth by a sprinkler irrigation system.
- The formula to compute system capacity is given by

$$Q = 2780 \times \frac{A \times d}{F \times H \times E} \qquad (2)$$

in which,

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 day^{-1}

E = water application efficiency, per cent

Sprinkler Discharge:

The discharge of a sprinkler is estimated by knowing the diameter of nozzle and operating pressure available at the nozzle by following formula.

$$Q = CA\sqrt{2gh} \qquad (3)$$

where,

Q = nozzle discharge, m^3/s

C = sprinkler discharge coefficient which vary from 0.80 to 0.95

A = cross-sectional area of nozzle or orifice, m^2

g = acceleration due to gravity, m/s^2, and

h = pressure head, m

Spread of Sprinkler:

The area covered by a rotating head sprinkler can be estimated from the formula stated in equation.

$$R = 1.35\sqrt{dh} \qquad (4)$$

where,

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

d = diameter of nozzle, m

h = pressure head at nozzle, m

The maximum coverage is attained when the jet emerges from the sprinkler nozzle at angle between 30^0 and 32^0.

Pressure Variation in Irrigation Pipe Line

- The performance of the sprinkler irrigation system is related to operating pressure.
- The uniform water application from a sprinkler required desired optimum pressure.
- Friction loss in pipes and fittings, and differences in elevation cause pressure to vary in a field.
- Friction loss causes the pressure to decrease in the downstream direction, while changes in elevation can cause either an increase or decrease in pressure due to pipe running on uphill or downhill.
- The difference in pressure between locations along pipe line can be estimated as

$$P_d = P_u - 9.81(h_l \pm \Delta Z) \qquad (1)$$

Where

P_d & P_u= pressure at down and upstream positions, respectively, kPa

h_l = energy loss in pipe between the up- and downstream positions, m

ΔZ = elevation difference, m (+ve for uphill & -ve for downhill)

Energy Loss

The energy loss (h_l) includes head loss due to friction and minor loss, which can be estimated as.

$$h_l = FH_f + M_1 \qquad (2)$$

where

F =constant; f (number of outlets and method used to estimate, H_f)

H_f = friction loss in pipe between up and downstream locations, m

M_1 = minor losses through fittings, m

Major and minor losses are two types of losses that occur in pipe flow.

Equations for Head Loss due to Friction

The Darcy-Weisbach, Hazen Williams or Scobey equation can be used to compute head loss due to friction, H_f. The general form of these equations can be written as

$$H_f = \frac{(K)(c)(L)(Q^m)}{D^{2m+n}} \qquad (5)$$

where

K = friction factor that depends on pipe material

L = length of pipe, m

Q = flow rate, L min^{-1}

D = diameter of pipe, mm

c, m, n = constants can be obtained from Table.

Table 1. Constants of friction loss equations (Source: James, 1988)

Equations for computing H_f	c	m	n
Darcy-Weisbach	277778	2.00	1.00
Hazen-Williams	591722	1.85	1.17
Scobey	610042	1.90	1.10

For the Darcy-Weisbach equation, K is given by the equation

$$K = 0.811\left(\frac{f}{g}\right) \qquad (6)$$

where,

f = friction factor can be obtained from the Moody diagram

g = acceleration due to gravity (9.81 m s^{-2})

K for Hazen-William equation is computed by

$$K = (0.285C)^{-1.852} \qquad (7)$$

where,

C = Friction coefficient depends on pipe material and diameter.

K for Scobey equation is given by

$$K = \frac{K_s}{348} \qquad (8)$$

where

Ks = friction factor values depends on pipe diameter and pipe material.

Friction loss in Pipes with Discharge Outlets

- **There will be less friction loss along a pipe with several equally spaced discharging outlets such as submains and laterals than along a pipe of equal diameter, length, and material with constant discharge (constant discharge means that inflow to the pipe section equals the outflow from the section).**

- **This occurs because the quantity of water in the submain or lateral diminishes in the downstream direction because of outlet discharge (i.e. drippers or sprinklers attached with laterals).**

- **The term F in equation (2) equals 1 when there are no outlets between the up and downstream locations along a pipe (i.e. discharge along the pipe is constant).**

The term F equals 1 when there are no outlets between the up and downstream locations along a pipe (i.e. discharge along the pipe is constant).

Equations 9 and 10 can be used to estimate F when there is more than one equally spaced outlet.

Equation 9 is used when the distance from the pipe line to the first outlet is equal to the outlet spacing.

$$F = \frac{1}{m+1} + \frac{1}{2N} + \frac{\sqrt{m-1}}{6N^2} \qquad (9)$$

Equation 10 is used when the distance to first outlet is half of the outlet spacing.

$$F = \frac{1}{(2N-1)} + \frac{2}{(2N-1)N^m} \sum_{i=1}^{N-1} (N-1)^m \qquad (10)$$

where

m = Exponent, m (can be obtained from Table 1) depending on type of equation involved in estimating H_f.

N = Number of emitters

When the discharge varies widely from outlet to outlet, the Equation (1) is applied between successive outlets working from the known pressure to unknown pressure.

Design of Lateral, Sub Main and Main Pipes

Lateral pipe Design

The Darcy-Weisbach friction factor, f, for small-diameter drip tubing is related to the Reynolds number, R_e the Reynolds number (R_e) is computed with the following equation.

$$R_e = \left(\frac{(\rho)(D)(V)}{(K)(\mu)}\right) \quad (11)$$

Where,

R_e= Reynolds number (dimensionless); D = diameter of pipe, cm;
ρ = density of water, g cm^{-3}; V = average velocity, cm s^{-1};
μ = viscosity of the fluid, N s m^{-2}; K = unit constant, 10 with these units

The equation used to compute friction factor (f) depends on the magnitude of N_R. For R_e less than 2000 (laminar flow), the friction factor

$$f = \frac{64}{R_e} \quad (12)$$

For R_e between 2000 and 1,00,000 (turbulent flow)

$$f = 0.32 {R_e}^{-0.25} \quad (13)$$

For R_e greater than 1,00,000 (fully turbulent flow)

$$f = 0.80 + 2.0 \log\left(\frac{R_e}{\sqrt{f}}\right) \quad (14)$$

The Hazen-Williams equation with C =150 can also be used to estimate head loss due to pipe friction R_e> 1,00,000.

Design of Sprinkler Laterals

In design of sprinkler laterals the pressure variation should not exceed more than 20% of the higher pressure.

The design capacity for sprinklers on a lateral is based on the average operating pressure.

The average pressure head, can be expressed approximately by

$$H_a = H_o + \frac{1}{4} H_f \qquad (6)$$

where, H_o = pressure at the sprinkler on the farthest end.

If the lateral is on nearly level land or on the contour, the head at the main is given

$$H_n = H_o + H_f \qquad (7)$$

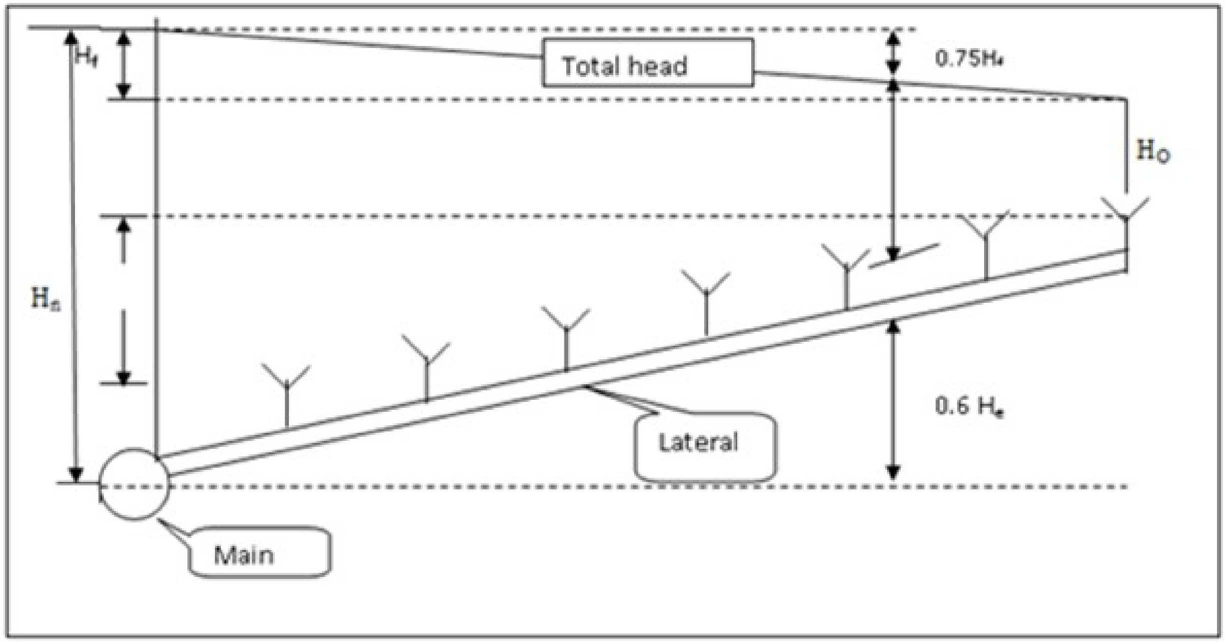


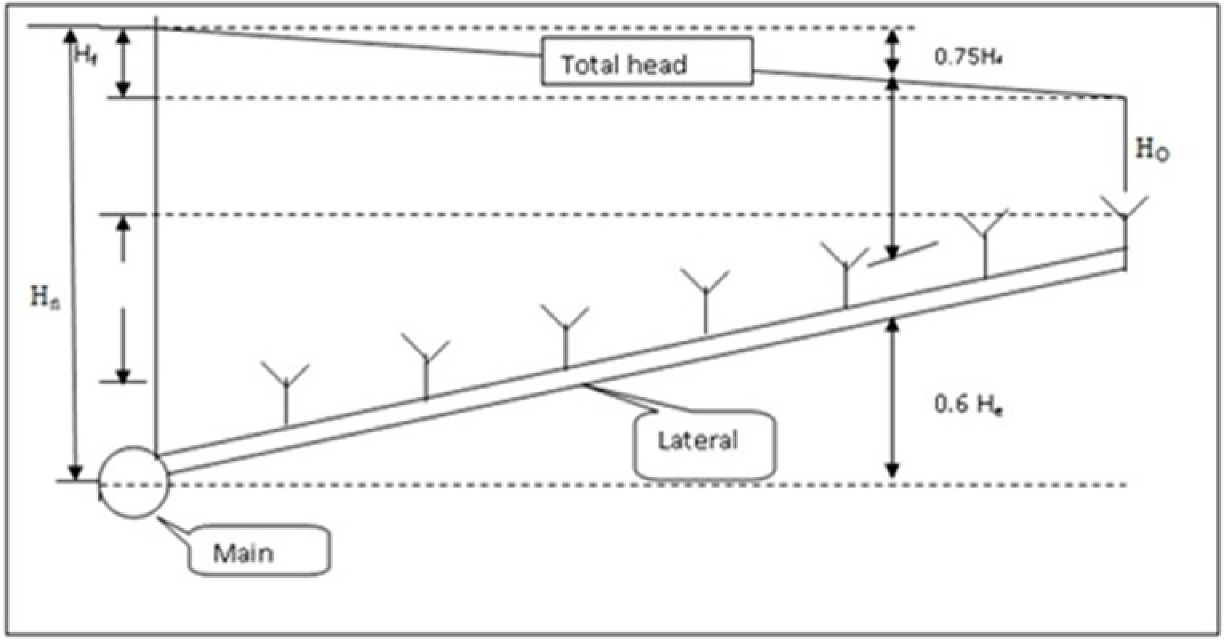
Fig. 38.1. Pressure profile in a lateral laid uphill. (Source: Michael, 2010)

Solving Equation (6) in terms of H_o and substituting in Equation 7 it becomes

$$H_n = H_a + \frac{3}{4}H_f \pm \frac{3}{4}H_e + H_r \qquad (8)$$

where,

- o H_a = Average pressure
- o H_f = Head loss due to friction in lateral pipe
- o H_n = Pressure required at the main to operate, m
- o H_e = Maximum difference in elevation between the first and last sprinkler on a lateral pipe, m
- o H_r = the riser height, m
- o The term $\frac{3}{4}H_e$ is positive if lateral is laid up slope and negative, if lateral is laid down slope



Design of Main Pipe

- ✓ Generally, sub main pipe supplies the water to sprinkler lateral and main supplies water to the sub main.
- ✓ If more numbers of sub mains are operated simultaneously at same time (a case for the large field) the procedure described for the design of the lateral may be used.
- ✓ However, when a single sub main is operated, the size of sub main and main pipe line is selected such that the annual operating cost and initial cost of the sub main line and mainline should be low.
- ✓ Normally friction loss of 3 m for small sprinkler system and 12 m for large sprinkler systems are used in design of main pipe line.

Pumps and Power Units

The suitable size of pump is selected considering the maximum total head against which the pump expected to operate and deliver the required discharge. This is be determined by

$$H_t = H_n + H_m \pm H_j + H_s \qquad (9)$$

where,

H_t = total design head against which the pump is working, m

H_n = maximum head required at the main to operate the sprinklers on the lateral at the required average pressure, including the riser height, m

H_m = maximum friction loss in the main and in the suction line, m

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

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

Calculation of Power Requirement

The horse power requirement of pump is given by

$$h_p = Q_t \times H_t / 75 \times n_P \qquad (10)$$

Q_t = total discharge, $L\ s^{-1}$,

H_t = total head, m

n_p = efficiency of pump(fraction)

Example 1:

Determine the required capacity of a sprinkler system to apply water at the rate of 1.25 cm/hr. Two 186 metres log sprinkler lines are required. Sixteen sprinklers are spaced at 12 metre intervals on each line. The spacing between line is 18 metres.

Solution:

The equation

$$q = \frac{s_l \times s_m \times I}{360}$$

$$= \frac{12 \times 18 \times 1.25}{360}$$

= 0.75 litres/sec/sprinkler

System capacity = total discharge of all sprinklers

=0.75×32

=24 litres/sec

Example 2:

Determine the system capacity for a sprinkler irrigation system to irrigate 16 hectares of maize crop. Design moisture use rate is 5 mm/day. Moisture replaced in soil at each irrigation is 6 cm. Irrigation efficiency is 70 percent. Irrigation period is 10 days in a 12-day interval. The system is to be operated for 20 hours per day.

Solution:

$$Q = 2780 \times \frac{A \times d}{F \times H \times E}$$

$$= 2780 \times \frac{16 \times 6}{10 \times 20 \times 70}$$

=19 litres/sec

Example 3:

Design a sprinkler irrigation system to irrigate 5 ha Wheat crop.

Assume

Soil type = silt loam,

Infiltration rate at field capacity = 1.25 cm h^{-1},

Water holding capacity = 15 cm m^{-1},

Root zone depth = 1.5 m,

Daily consumptive use rate = 6 mm day^{-1},

Sprinkler type = Rotating head.

Solution:

Step I

- Given infiltration capacity =1.25 cm h^{-1}
- Hence maximum water application rate = 1.25 cm/h

Step II

- Total water holding capacity of the soil root zone = 15 x 1.5 = 22.5 cm
- Let the water be applied at 50% depletion, hence the depth of water to be applied = 0.50 x 22.5 = 11.25 cm
- Let the water application efficiency be 90 per cent
- Depth of water to be supplied = 11.25 / 0.9 = 12.5 cm

Step III

- For daily consumptive use rate of 0.60 cm
- Irrigation interval = 11.25 / 0.6 = 19 days
- In period of 19 days, 12.5 cm of water is to be applied on an area of 5 ha.
- Hence assuming 10 hrs. of pumping per day, the sprinkler system capacity would be
- $Q = 2780 \times \frac{A \times d}{F \times H \times E}$
- $Q = 2780 \frac{5 \times 12.5}{19 \times 10 \times 100} = 9.145\ l/s \approx 0.009\ m^3/s$

Step IV

Let the spacing of lateral (S_m) = 18 m,

Spacing of Sprinklers in lateral (S_l) = 12 m

This selection is based on using following consideration:

Operating pressure of nozzle = 2.5 kg cm^{-2}

Maximum application rate = 1.25 cm h^{-1}

Referring sprinkler manufacturer's M/S NOCIL, Akola, India, the nozzle specifications with this operating pressure and application rate is:

Nozzle size : 5.5563 x 3.175 mm

Operating pressure : 2.47 kg/cm^2 and

Application rate : 1.10 cm hr^{-1} (which is less than the maximum allowable application rate of 1.25 cm h^{-1})

Diameter of coverage : 29.99 ≈ 30.0 m

Discharge of the nozzle : 0.637 L s^{-1} = 0.637 x 10^{-3} m^3s^{-1}

Step V

Total no. of sprinkler required = $\frac{0.009}{0.637\times10^{-3}}$ = 14.12 ≈ 14 sprinklers

Considering two sprinkler laterals, therefore 7 sprinklers on each lateral.

Step VI

Considering the sprinklers are spaced at 12 m intervals on each lateral and the lateral lines are at 18 m spacing.

Step VII

Total length of each lateral = 12 x 7 = 84

Operating pressure = 2.47 kg cm^{-2}

Total allowable pressure variation in the pressure head is 20%, hence maximum allowable pressure variation in pressure = 0.2 x 2.47 = 0.494 kg/cm^2 = 4.94 m

Assume pressure variation due to elevation = 2 m

Permissible head loss due to friction = 4.94 – 2 = 2.94 m

Total flow through the lateral = 7 x 0.637 x 10^{-3} = 4.459 x 10^{-3} m^3s^{-1}

Reduction factor (F) = $\frac{1}{3} + \frac{1}{2\times7} + \frac{1}{6\times7^2}$ = 0.333 + 0.071 + 0.0034 = 0.407

Head loss due to friction = using Darcy's Weisbach equation and reduction factor.

$$H_f = \frac{0.811\times0.04\times277778\times84\times(4.459\times60)^2}{9.81\times D^5} \times 0.407$$

$$F = \frac{1}{m+1} + \frac{1}{2N} + \frac{\sqrt{m-1}}{6N^2}$$

$$H_f = \frac{(K)(c)(L)(Q^m)}{D^{2m+n}}$$

Equations for computing H_f	c	m	n
Darcy-Weisbach	277778	2.00	1.00
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Scobey	610042	1.90	1.10

Frictional head loss in main pipe line (H_f) = 30.6 × 0.2 = 6.12 m

Calculating in the same way as done in case of lateral

$$6.12 = \frac{0.811 \times 0.04 \times 277778 \times 36 \times (0.009 \times 1000 \times 60)^2}{9.81 \times D^5} \times 0.407$$

$$D^5 = \frac{0.811 \times 0.04 \times 277778 \times 36 \times (0.009 \times 1000 \times 60)^2}{9.81 \times \ 6.12} \times 0.407$$

or

D = 69.10 ≈ 75 mm

Total design head (H) = $H_m + H_f + H_j + H_s$

Where,

H_j = Difference in highest junction point of the lateral and main from pump level = 0.5 m (assume)

H_s = Suction lift (20 m, assume)

H = 30.6 + 6.12 + 0.5 + 20 = 57.22 m

or $2.94 = \frac{0.811 \times 0.04 \times 277778 \times 84 \times (4.459 \times 60)^2}{9.81 \times D^5} \times 0.407$

$$D^5 = \frac{0.811 \times 0.04 \times 277778 \times 84 \times (4.459 \times 60)^2}{9.81 \times 2.94} \times 0.407$$

D = 59.79 ≈ 63 mm

Hence diameter of lateral = 63 mm

Assume height of riser pipe =1 m

The head required to operate the lateral lines (H_m) = 24.7 + 2.94 + 2 + 1 = 30.6 m

Frictional head loss in main pipe line (H_f) = 30.6 × 0.2 = 6.12 m

Calculating in the same way as done in case of lateral

$$6.12 = \frac{0.811 \times 0.04 \times 277778 \times 36 \times (0.009 \times 1000 \times 60)^2}{9.81 \times D^5} \times 0.407$$

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H = 30.6 + 6.12 + 0.5 + 20 = 57.22 m

The pump has to deliver 0.009 m^3s^{-1} of water against a required head of 57.22 m

Hence, the horse power of a pump at 60% efficiency

$$= \frac{0.009 \times 57.22 \times 10^3}{0.6 \times 75}$$

=11.44 hp

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Thank You !