HANDBOOK
OF
SPRINKLER IRRIGATION SYSTEMS

PART-I: SPRINKLER IRRIGATION TECHNOLOGY,
HYDRAULICS AND
DESIGN OF RAINGUN SYSTEMS

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WHY DESIGN IS IMPORTANT

Sprinkler irrigation systems require high initial investment and are energy intensive compared to surface irrigation systems. These systems are also complex in operation to meet crop water requirement within economical range.

The objectives of designing any sprinkler irrigation system suitable to the local environment and socio-economic conditions are to: a) apply water to meet peak crop water requirement; b) maintain application and uniformity efficiency at a desired level; c) energy and water efficient to keep initial and operation cost as low as possible; and d) simple in operation and maintenance so that farmers can use these systems without extensive training.

The purpose of this handbook is to provide information about systems classification, adaptation in Pakistan, parameters involved in the selection and design of raingun sprinkler systems, system design and manufacturer's specifications. Also included is the information about the solid-set raingun sprinkler systems. This information will help agricultural and irrigation engineers to design appropriate systems considering farmers requirements and farm layout. Some changes can be made, if desired, to meet farmers requirement especially the prime mover and pumping systems, if these already exist with the farmers. However, booster pumps can be used to enhance pressure if electricity is available.

At the end, I would like to acknowledge the contributions made by the engineers of the Water Resources Research Institute especially Mr. M. Yasin, Mr. P.M. Moshabbir, Mr. Asif Ali Bhatti, Mr. M. Aslam, Mr. Munir Ahmad and Mr. Azmatuliah Khan in the
design, local manufacturing and testing of raingun systems in Pakistan. I hope that the team members will continue further work to refine this handbook in future. The contributions made by Mr. Tariq Mustafa in computer aided drawings and Mr. Khalid Mahmood in typing the manuscript are highly acknowledged. The initiative taken by Mr. Tariq Mustafa in computer aided drawings and designs will help to further refine the technology in future. The readers and users are requested to provide comments and suggestions to improve this handbook.

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I. SPRINKLER IRRIGATION TECHNOLOGY

Irrigation is often designed to maximize efficiency and minimize the labour and capital requirements of a particular irrigation system and, at the same time, maintain a favourable growing environment for the crop. Some managerial inputs are dependent on the type of irrigation system and the design of the system. For example, the degree of automation, the type of system, soil type, topographical variation and management tools can influence the managerial decisions. The management decisions, which are common to all sprinkler systems, regardless of the types, are the frequency of irrigation, depth of water to be applied, and measures to increase the uniformity of application. In addition, individual sprinkler systems can be manipulated to greatly increase application efficiencies.

In recent years, irrigation scheduling services have helped the farm manager with decisions on how much to apply and how frequently. Irrigation practices such as pre-irrigation (Rauni) before planting, irrigation to ensure emergence or the length of time per sprinkler set, are managerial inputs which influence water use efficiency over the season.

1.1 SELECTION CRITERIA

There are a large number of considerations which must be taken into account in the selection of an irrigation system. These factors vary in importance from location to location and crop to crop. Briefly, these considerations include the compatibility of
the system with other agricultural operations, economic factors, topographic limitations, soil properties and agronomic influences.

The irrigation system for a field/farm must be compatible with the other existing farm operations such as land preparation, cultivation and harvesting practices. For instance, the use of the more efficient, large machinery requires longer and wider fields.

1.2 ECONOMIC CONSIDERATIONS

The type of irrigation system selected is also an economic decision. Some types of sprinkler systems have high per hectare costs and their use is, therefore, limited to high value crops. Other systems have high labour requirements, and some have fairly high operating costs.

Also, some systems have limitations with respect to the type of soil or the topography on which they can be used. The expected life of the system, fixed costs, and annual operation costs should also be included in the analysis while selecting an irrigation system.

1.3 TOPOGRAPHIC LIMITATIONS

Restrictions on irrigation system selection due to topography include groundwater levels, the location and relative elevation of the water source, field boundaries, area of each field, the location of roads, electricity and water lines, shape of the field, and field slope. The slope of the land is very important. Some types of sprinklers can operate on slopes up to 20 percent or more.

The shape of a field also determines the type of system. For instance, solid-set sprinklers can be adjusted to fit almost any
field shape; whereas, a centre-pivot sprinkler must have approximately round-shaped fields. For a sideroll sprinkler, the field should be approximately rectangular in shape.

1.4 SOIL CHARACTERISTICS

The soil type, soil moisture holding capacity, the intake rate, and effective soil depth are the important factors for the type of system selected. For example, sandy soils have a high intake rate and accept high volume sprinklers which would be unacceptable on a clay soil.

The moisture-holding capacity will influence the size of the irrigation sets and frequency of irrigations as evidenced by a sandy soil with low moisture-holding capacity which requires frequent and light applications of water. A centre-pivot or sideroll sprinkler system would perform satisfactorily in this case.

A number of other soil properties are also significant factors in considering the type of irrigation system that will be most advantageous in a particular situation. The interaction of water and soils due to physical, biological, and chemical processes has some influence on the hydraulic characteristics and tilth. Crusting and erodibility should be considered in each irrigation system design, and the spatial distribution of soil properties may be an important limitation on some methods of applying irrigation water.

1.5 WATER SUPPLY

The quality, quantity, and temporal distribution characteristics of the source of irrigation water have a
significant bearing on the irrigation practices. Crop water requirements are essentially continuous during the growing season although varied in magnitude. A small, readily available water supply is best utilized in a small capacity irrigation system which incorporates frequent applications. The depths applied per irrigation are, therefore, small in comparison to system having a large discharge available less frequently.

The quality of the water in conjunction with the frequency of irrigations must be evaluated. Salinity is generally the most significant problem. A highly saline water supply must be applied more frequently and in large amount than a good quality water.

1.6 CROP FACTORS

Some of the factors associated with the crops being grown which influence the choice of irrigation system and its eventual management are summarized in the following lines:

* tolerance of the crop during both development and maturation to soil salinity and aeration;
* magnitude and temporal distribution of water needs for maximum production; and
* economic value of the crop.

1.7 SELECTION OF A SYSTEM

With careful consideration of the factors outlined above and others as the particular circumstance dictates, the right type of irrigation system can be selected. The array of available sprinkler systems makes this method of irrigation compatible in nearly any situation. For fields planted to trees, vines, or other perennial
crops of similar nature, permanently located systems can operate effectively. Crops like berseem, sugarcane, or grains are best irrigated by a system whose parts can be moved away from the necessary cultural operations.

Sprinkler irrigation systems are high initial investment and energy intensive. On the other hand, they are labour, water and fertilizer efficient. No expenditure requires for land levelling, but usually have maintenance requirements that can be more expensive than for surface irrigation systems. A major economic factor is the utility of the sprinkler systems in providing a cost-effective means of fertilizer and pesticide applications, and the control of plant environments through frost control and cooling.

The cost of sprinkler irrigation systems is minimized when operated continuously during the critical demand period. Thus, these systems tend to favour conditions where the water supply is readily available. Applications tend to be smaller than with surface methods which not only minimize system capacity, but reduces the consequences of shallow or badly stratified soils.

1.8 ADVANTAGES/DISADVANTAGES

Sprinkler irrigation systems are recommended and used on practically all types of soil, topographic conditions, and on almost all kinds of crops. Its flexibility and efficient water control has permitted a wider range of soils to be irrigated that have surface water application methods, thereby allowing more land to be classed as irrigable. As a direct result, thousands of hectares of land in the United States which was previously suitable
only for dryland farming or as wasteland, is being irrigated today with high yield. This is particularly evident in eastern Colorado, western Nebraska and Kansas. Similar beginning is already made in the Pothwar plateau to provide supplemental irrigation to Barani lands.

On some saline soils, as in the Imperial Valley of California, sprinklers are recommended for better leaching and crop germination. Sprinklers are especially desirable where soils have a high permeability and/or low water holding capacity. Sprinklers can offer distinct advantages over other irrigation methods in dense soils with low permeabilities. In areas where labour and water costs are high, sprinklers can be the most economical way to apply water. In many cases, sprinklers have been shown to increase yield, such as in the fresh vegetables and fruit market where colour and quality are very important.

Sprinklers often have multiple uses. The same equipment can be used for irrigation, crop coolings, frost control, and the application of pesticides, herbicides and fertilizers. In addition, modern farming practices which require large equipment and large fields for economical farming operations are easily irrigated by sprinklers with no reduction in efficiency. Many areas in the United States, which annually receive more than enough precipitation the satisfy crop requirements, are installing supplemental irrigation systems. This is due to the fact that usually there is no rain at exactly the right time in the required quantity. A timely irrigation at a critical crop growth stage,
applying only a few centimeters of water, can offer more than double yield.

Sprinklers, like most physical systems, do have disadvantages. Damage to some crops has been observed when poor quality irrigation water is applied to the foliage by sprinklers. Poor quality water can leave undesirable deposits or colouring on the leaves or fruit of the crop. Sprinklers are also capable of increasing the incidence of certain crop diseases such as fire blight in pears, fungi or foliar bacteria. A major disadvantage of sprinklers is the relatively high cost, especially for solid-set systems, in comparison to surface irrigation methods. When gravity cannot supply sufficient head to operate the system, sprinklers can require large amount of energy to supply the necessary pressure. The advantages and disadvantages of sprinkler systems must be assessed economically with other irrigation methods. Likewise, individual types of sprinkler systems should be compared to one another.

1.9 SYSTEMS' CLASSIFICATION

Sprinkler systems can be classified in such ways as portability, field layout, equipment used, and type of system being irrigated. Some researchers have found portability a useful criteria for describing the available sprinkler irrigation systems. Under this classification, a system is fully portable when all of the system components can be moved and fully permanent when none of them can. In the ensuing lines, a number of the more popular sprinkler systems are described using portability as the basis for
1.9.1 Solid-Set System

A sprinkler system which remains in a single location during an irrigation season and supplied by a fixed network of pipes is generally regarded as a solid-set system. There is no unique field layout for solid-set system because of the many ways the piping system can be arranged, but there are two basic types of components - aluminium and plastic. Aluminium piping is typically laid along the ground surface and collected to provide access for cultivation type farming practices. Plastic pipes, usually PVC, are nearly always buried permanently because sunlight deteriorates the pipe. If UV stabilizers and black carbon are added LDPE pipes can be installed on the surface.

Solid-set systems irrigate the entire field with a single set of components and are, therefore, more costly than most other sprinkler piping. The labour and maintenance requirements of solid-set systems are minimal, but cultural operations such as cultivation, spraying, planting and harvesting may be restricted. As a result, solid-set systems are mostly applicable for crops with minimum cultural practices requirements.

1.9.2 Move-stop Systems

To reduce equipment needs and minimum interference with other farming operations, many sprinkler systems are designed to move the lateral pipelines from set to set. The movement itself can take on any form from the hand-moved lateral to the tractor-towed lateral
to the motor-moved lateral; hence, the common use of names like
hand move, end tow and sideroll sprinkler systems.

Move-stop systems require more labour and maintenance than
solid-set systems, but are less expensive to purchase and install.
Energy requirements are approximately equivalent. The major
disadvantage is the need to move the system from wet to dry areas
which not only increases the necessary capacity of the network but
also tends to reduce crop yields by damaging the crops.

1.9.3 Continuous-Move Systems

A remedy to the labour, maintenance, and down-time problems
with move-stop systems is the system that covers the irrigated area
by continuously moving. Centre-pivot, linear move, and big gun
systems are typical examples of the continuous move concept.
Although the equipment must be automated and made mobile, some
reduction in pipe lengths and pipe sizes is possible to offset
higher equipment costs.

The major advantage of the continuous-move system is labour-
saving. On a smaller scale, the sweeping action of these systems
also tends to improve the irrigation uniformities. Early systems
were plagued by mobility problems, sticky soils and difficulty in
maintaining alignment. Today, a major problem is high precipitation
rates leading to excessive field runoff and high energy
requirements. Nevertheless, the continuous move systems are the
most popular and most widely used sprinkler systems in agricultural
applications in the United States and many other countries.
II. FEASIBILITY OF SPRINKLER IRRIGATION IN PAKISTAN

2.1 OUTSIDE INDUS BASIN COMMAND AREA

The initial capital cost of the sprinkler irrigation equipments is its limitation for large-scale adoption in Pakistan. Therefore, the high cost and economic consideration limit the use to fruit trees and vegetables of high value in specific problem areas. These include:

- areas of Balochistan province where the value of water is high and high value crops are grown;
- green belt areas around Karachi where high value vegetables and fruits are grown;
- undulated sandy lands in the Thal and Cholistan desert which are underlain with groundwater of reasonable quality;
- sandy and undulating riverain area;
- un-commanded sandy high areas within Indus Basin;
- fringe areas of Indus Basin where water is either saline or extremely scare; and
- Northern Areas where high value crops are grown on sloppy terraces with very coarse textured soils.

The inefficiency of surface irrigation, probably 20 percent or less on sandy rough lands, is well known. Thus, the attractiveness of highly controlled sprinkler irrigation is obvious which has the potential to increase efficiency to 85 percent. Furthermore, the use of sprinklers which utilize pipe to convey the water, makes the development of the most sandy lands and rough topography practical even with relatively saline water. Thus, existing water supplies can be greatly extended and a totally new class of lands becomes
available for irrigation and can be made available for development by application of sprinkler technology. There is little question as to the technical feasibility of sprinkler systems which have already been substantiated on extensive installation throughout the world. The question we face is whether such systems or special adaptations are sociologically and economically practical for Pakistan at the present.

The cost of the system depends mainly on the spacing of laterals. The cost of the unit and the net return from the crop should be compared before a decision is made on installing sprinkler irrigation system. The main item of expenditure is the cost of the lateral lines.

2.2 INDUS BASIN COMMAND AREA

Inefficient water conveyance and field application by surface irrigation in the Indus Basin has created problems which are as follows:

- waterlogging;
- waste of available water resources;
- salinization of land and water;
- low crop yields; and
- expensive programmes to control problems caused by inefficient water utilization.

Because of these problems and due to increasing demands for additional irrigation development, there is an urgent need to control canal seepage losses, improve field water application efficiency, and establish good irrigation practices.
At present, there are development programmes to control water losses from the extensive water delivery system in the Indus Basin. On the other hand, relatively little work is being done to establish efficient irrigation practices. Therefore, efforts are needed to improve existing surface irrigation and introduce sprinkler system of simple operation adaptable to farmers and crops and to physical conditions of the country. If we include the investments needed for land development and drainage in the Indus Basin, the investments required for the installation of sprinkler irrigation system seem feasible.

2.3 SPRINKLER IRRIGATION IN PAKISTAN

Sprinkler irrigation is being introduced in the country. It has been installed in several demonstration plots in the country. Furthermore, progressive farmers are importing sophisticated systems such as centre pivots and linear move sprinkler machines.

The conventional sprinkler irrigation systems are capital intensive. Therefore, some modifications are needed to suit the socio-economic conditions and physical requirements in Pakistan. The sprinkler system can be used with gravity flow where hydraulic head is available which will reduce the initial cost. Such locations are available in Norther Areas, NWFP and Balochistan.

The sprinkler irrigation system can be easily introduced for high value vegetables and fruits in areas where either value of water is high or soils are of light texture. Later on, the system can be extended to field crops if the economic conditions permit
its installation. The recommended systems for various physical, social and economic conditions are presented in Table 1.

Table 1. Recommended raingun sprinkler systems for various physical and socio-economic conditions in Barani areas.

<table>
<thead>
<tr>
<th>Farm Size (acres)</th>
<th>Raingun Model</th>
<th>Working Pressure (m)</th>
<th>Prime Mover</th>
<th>Area Coverage Per Setting (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>PY₁-20</td>
<td>40</td>
<td>Electric</td>
<td>0.40</td>
</tr>
<tr>
<td>5.0</td>
<td>PY₁-20</td>
<td>40</td>
<td>Electric</td>
<td>0.64</td>
</tr>
<tr>
<td>10.0</td>
<td>PY₁-40</td>
<td>45</td>
<td>Electric</td>
<td>1.00</td>
</tr>
<tr>
<td>15.0</td>
<td>PY₁-50</td>
<td>50</td>
<td>Electric</td>
<td>1.40</td>
</tr>
<tr>
<td>20.0</td>
<td>PY₁-60</td>
<td>60</td>
<td>Electric</td>
<td>1.83</td>
</tr>
<tr>
<td>25.0</td>
<td>PY₁-60</td>
<td>60</td>
<td>Electric</td>
<td>2.10</td>
</tr>
<tr>
<td>30.0</td>
<td>PY₁-80</td>
<td>70</td>
<td>PTO driven</td>
<td>2.50</td>
</tr>
<tr>
<td>50.0</td>
<td>PY₁-80</td>
<td>80</td>
<td>PTO driven</td>
<td>3.80</td>
</tr>
</tbody>
</table>

Most of the system components of solid-set, hand move and raingun sprinklers have been successfully manufactured in Pakistan, except the cost effective aluminium pipes would need to be imported. The NARC-Water Resources Research Institute, Islamabad in collaboration with MECO Pvt. Ltd. Lahore developed a complete range of raingun sprinkler systems using locally available materials and technology. The high pressure low density polyethylene pipes with
black carbon and UV stabilizers were produced in collaboration with Griffon Industrial Corporation, Lahore. These are available in 25, 50, 75 and 100 mm diameter which can be used for pressures upto 120 psi. In the near future, other low pressure systems will be developed. The anticipated installed cost of portable raingun sprinkler system in Pakistan will be in the range of Rs. 5000-6000 per acre for a system of atleast 10 acres using diesel operated pumping system. The cost of electric operated systems will be in the range of Rs. 3000-4000 per acre for a system of 5 acres or more.
III. PIPELINE HYDRAULICS AND DESIGN EQUATIONS

3.1 INTRODUCTION

Energy losses occur in the pipeline due to friction and elevation changes. The change in energy in the pipeline between two points, is described by the Bernoulli Equation.

\[ \frac{V^2}{2g} + Z_1 + H_1 + \frac{V^2}{2g} = \frac{V^2}{2g} + Z_2 + H_2 + hf \]  

\[ (1) \]

in which,

- \( Z \) = elevation above an arbitrary datum, m;
- \( H \) = pressure head defined as the pressure divided by the specific weight of water, m;
- \( V \) = velocity of flow, m/sec;
- \( g \) = gravitational constant, 9.81 m/sec\(^2\); and
- \( hf \) = frictional headloss.

For constant flow conditions the equation (1) reduced to:

\[ H_1 = H_2 + hf + (Z_2 - Z_1) \]  

\[ (2) \]

3.2 BASIC SYSTEM HYDRAULICS

The sprinkler irrigation system designer has two principal hydraulic problems: 1) evaluation of pipe flow without multiple outlets (mains, submains, and auxiliaries); and 2) evaluation of pipe flow with multiple outlets (laterals and manifolds). The basis for design will be the selection of pipe sizes such that energy losses do not exceed prescribed limits ensuring that efficiencies and uniformities will be high.
3.2.1 Fundamental Flow Equations

The flow of water in pipes is always accompanied by a loss of pressure head due to friction. The magnitude of the loss depends on the interior roughness of the pipe walls, the diameter of the pipe, the viscosity of the water, and the flow velocity. These factors are lumped into friction coefficients based on experimental data.

There are several common equations for computing headloss in pipelines. Probably the most commonly used equation in irrigation calculations is the Hazen - Williams formula:

$$ hf = \frac{K(Q/C)^{1.852}}{D^{4.87}} \cdot L $$

in which,

- $K = 1.21 \times 10^{10}$;
- $Q =$ pipeline discharge, lps;
- $C =$ friction coefficient for continuous pipe sections, 120-140 for plastic manifolds and laterals, 140-150 for main lines without discharging outlets;
- $D =$ inside diameter, mm;
- $L =$ pipeline length, m; and
- $hf =$ frictional head loss, m.

The Hazen-Williams substantially underestimates friction losses when the Reynolds number approaches the laminar range of values. A more correct equation is the Darcy-Weisbach:

$$ hf = \frac{L V^2}{f D^2 g} $$

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Where,

\[ L = \text{pipe length, m}; \]
\[ D = \text{pipe diameter, m}; \]
\[ V = \text{average flow velocity, m/sec}; \]
\[ g = \text{gravitational constant, 9.81 m/sec}^2; \text{ and} \]
\[ f = \text{frictional factor}. \]

The friction coefficient, \( f \), is determined as a function of the Reynolds number and the relative roughness of the pipe. The Reynolds number can be calculated using:

\[
Re = 1.26 \times 10^6 \times \frac{Q}{D}
\]

in which;

\[ Re = \text{Reynolds number}, \]
\[ Q = \text{pipe discharge, lps}; \text{ and} \]
\[ D = \text{inside pipe diameter, mm}. \]

Then the value of \( f \) is determined as follows:

\[
f = \frac{64}{Re} \quad \text{for } Re < 2100
\]

\[
f = 0.04 \quad 2100 < Re < 3000
\]

\[
f = \frac{0.32}{Re^{0.25}} \quad 3000 < Re < 10^5
\]

and

\[
f = \frac{0.13}{Re^{0.172}} \quad 10^5 < Re < 10^7
\]
Substitution of Eqns. 6, 7, 8 and 9 into (4) resulted into simplified expression.

\[
\frac{A_i \cdot Q_{mi} \cdot L}{D_p^3} \quad (10)
\]

where,

<table>
<thead>
<tr>
<th>i</th>
<th>Ai</th>
<th>Pi</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.1969 \times 10^3</td>
<td>4.0</td>
<td>Re &lt; 2100</td>
</tr>
<tr>
<td>2</td>
<td>3.3051 \times 10^6</td>
<td>5.0</td>
<td>2100 &lt; Re &lt; 3000</td>
</tr>
<tr>
<td>3</td>
<td>7.8918 \times 10^5</td>
<td>4.75</td>
<td>3000 &lt; Re &lt; 10^5</td>
</tr>
<tr>
<td>4</td>
<td>9.5896 \times 10^5</td>
<td>4.828</td>
<td>10^5 &lt; Re &lt; 10^7</td>
</tr>
</tbody>
</table>

Hazen-William (C = 140) \( 1.283 \times 10^6 \) 4.852 \( 10^5 < Re < 10^7 \)  

and 

\[
\text{mi} = \text{Pi} - 3 \quad (11)
\]

Friction losses are also induced in the pipelines due to fittings, bends, changes in cross-sectional area, and entrances. These are generally evaluated as a function of velocity head in the pipe as follows:

\[
h_f' = K_f \frac{V^2}{2g} \quad (12)
\]

The values of \( K_f \) are presented in Appendix-V.
3.2.2 **Headloss in Pipes With Multiple, Equally Spaced Outlets**

The flow of water in a pipe having multiple, equally spaced outlets will have less headloss than a similar pipe transmitting the entire flow over its length because the flow steadily diminishes each time an outlet is passed. Computations start from the distal outlet. Christiansen developed the concept of a "F factor" which accounts for the effect of the outlets. When the first outlet is one outlet spacing from the lateral or manifold inlet:

\[
F = \frac{1}{m+1} + \frac{1}{2N} + \frac{\sqrt{m-1}}{6N^2} \tag{13}
\]

in which,

- \( F \) = fraction of the headloss under constant discharge conditions expected with the multiple outlet case;
- \( m = 1.85 \) for Hazren-Williams equation;
- \( m = 2.0 \) for the Darcy-Weisbach equation; and
- \( N \) = number of outlets along the pipe.

For situation where first outlet is only one-half the spacing from the inlet and.

\[
F' = \left(\frac{2N}{2N-1}\right) F - \left(\frac{1}{2N-1}\right) \tag{14}
\]

The pressure headloss in the pipe having multiple outlets is found by computing the headloss using the inlet discharge and then multiplying this value by \( F \) or \( F' \).
3.2.3 Pressure Distribution Assuming Constant Outlet Flow

The flow conditions in lateral and manifold lines are generally steady and spatially varied, with decreasing discharge along the line. The discharge at any point along the pipe can be expressed.

\[ Q_L = \left(N - \frac{L}{S_s}\right)q \]  \hspace{1cm} (15)

\[ L = N \cdot S_s \]  \hspace{1cm} (16)

\[ Q_L = \frac{q}{S_s} (L - L') \]  \hspace{1cm} (17)

in which,

- \( Q_L \) = pipe discharge at a particular point, lps;
- \( L' \) = distance measured from the inlet end, m;
- \( S_s \) = sprinkler spacing, m;
- \( N \) = total number of sprinklers along the pipe; and
- \( q \) = sprinkler discharge, lps.

The pressure distribution in the lateral or manifold can be described in terms of the pressure at a distance \( L' \) meter from the pipe inlet.

\[ H_L = H_1 - R_L \frac{L'}{L} \cdot h_r + (Z_1 - Z_2) \]  \hspace{1cm} (18)

where,

- \( H_1 \) = pressure at the inlet, m;
- \( Z_1, Z_2 \) = elevation at the pipe inlet and its distal end, respectively, m;
- \( R_L \) = friction drop ratio;
\[ L' = \text{any point distance from inlet, and} \]
\[ h_f = \text{total headloss in pipe.} \]

and

\[ h_f = \frac{aL^{p_i-2}}{Pi-2} \quad (19) \]
\[ a = \frac{Ai(q/S_s)^{p_i-3}}{D^{p_i}} \quad (20) \]
\[ \frac{L-L'}{L} \quad (21) \]

3.3 FRICTION LOSS INPIPES WITH MULTIPLE DIAMETERS

It is often possible to design irrigation pipelines with two or more diameters in order to achieve a desired headloss in the pipe network.

Consider a pipeline of length \( L \) consisting of two pipe diameters, \( D_L \) and \( D_s \), representing large and small pipes, respectively. Large pipe always at the upstream of the small pipe.

Then

\[ L = L_L + L_s \quad (22) \]
\[ N_L = \frac{L_L}{S_s} \quad (23) \]
\[ N_s = \frac{L_s}{S_s} \quad (24) \]

The procedure for calculating the headloss utilizes equations (4) and (14) as follows:
a) Calculate the headloss for the flow in the smaller pipe:

\[(hf)_s = h_f (D_s, Q_s, L_s). F (N_s, m) \quad (25)\]

b) Calculate the headloss for the flow of the small pipe but in the large diameter pipe:

\[(hf)_L = h_f (D_L, Q_s, L_s). F (N_s, m) \quad (26)\]

c) Calculate the headloss for the inlet flow to the large pipe having a length equal to L:

\[(hf)_L = h_f (D_L, Q, L). F (N, m) \quad (27)\]

d) Then, the total pressure headloss is:

\[h_f = (hf)_s - (hf)_L + (hf)_L \quad (28)\]

3.4 SPRINKLER SYSTEM DESIGN EQUATIONS

Sprinkler system design is somewhat of an iterative procedure in which successive adjustments to the design may be made to correct a deficiency that may show up in checking the designs. There will be several alternative designs that will satisfy the field criteria.

The capacity of the sprinkler system is based on the 10 day average peak demand. At each irrigation, the gross depth to apply is given as:
Where

\[
Da = \frac{f \cdot TAW}{Ea}
\]

(29)

and

\[
Ea = \text{application efficiency expressed as a fraction.}
\]

The frequency with which this depth must be applied is:

\[
I_i = \frac{f \cdot TAW}{E_t}
\]

(30)

in which

\[
I_i = \text{irrigation interval in days; and}
\]

\[
E_t = \text{design } E_t \text{ rate, mm/day.}
\]

For stationary sprinkler systems, the sprinkler application rate can be determined by:

\[
d = \frac{Da \cdot N' \cdot E_t}{I_i \cdot T_d} \cdot \frac{N' \cdot E_t}{E_a \cdot T_d}
\]

(31)

Where

\[
d = \text{average application rate, mm/hr;}
\]

\[
N' = \text{number of sets per irrigation; and}
\]

\[
T_d = \text{number of hours per day the system operates.}
\]

The Kostiakov infiltration function is described as:
Z = a T^b \tag{32}

Where

\begin{align*}
Z &= \text{cumulative infiltration, mm;} \\
T &= \text{hours since infiltration begins; and} \\
a, b &= \text{empirical functions}
\end{align*}

The total number of sprinkler in operation at one time, \( N_s \), should be limited by:

\[ N_s = \frac{Q_l}{q_s} \tag{33} \]

Where

\begin{align*}
Q_l &= \text{discharge of manifold or lateral line, lps;} \\
q_s &= \text{sprinkler discharge, lps; and} \\
N_s &= \text{number of sprinklers.}
\end{align*}
IV. RAINGUN SPRINKLER SYSTEMS

4.1 INTRODUCTION

The Raingun sprinkler irrigation system is designed to provide irrigation in areas where surface irrigation is either not possible or huge investments are required for land forming. In Barani areas, the yields of major crops are 30-50% of the national average yields mainly because of drought and lack of available moisture at critical crop growth stages. The planting of crops is normally delayed due to lack of moisture and farmers do wait for rainfall. The plant population is also low due to non-uniform and inadequate moisture in un-leveled fields. In certain areas, the crop failures are also common, if dry spells are prolonged.

Considering problems of low crop yield and low cropping intensity, there is a need to introduce supplemental or life saving irrigation in areas where water is available. Water is available through dugwells, tubewells, mini/small dams, lakes and nullahs. At present, there are around 24 small and 94 mini dams in the Punjab Barani tract. But due to non-availability of an appropriate irrigation system, only 30 and 10% of the designed command area of small and mini dams, respectively, have been developed for irrigation.

Some farmers are practicing lift irrigation. But due to insufficient engineering and scientific support available for land forming farmers are facing difficulty to form their lands for surface irrigation. The only option left for Barani areas is to use sprinkler irrigation because water is of high value in these areas.
Therefore, the need arise to reduce irrigation input because operational cost of sprinkler irrigation will certainly increase cost of production. Therefore, it is important to efficiently use available rainfall with an objective to reduce irrigation input. This may require conjunctive use of rainfall and sprinkler irrigation with an objective to reduce the cost of production and optimize farmers' net return in Barani areas.

For sustainable Barani farming, the development of conservation terrace farming system is a pre-requisite. Therefore, efforts must be made to develop an integrated strategy for increasing crop production and cropping intensity in Barani Areas.

In this handbook efforts have been made to present some of the designs for electric motor and diesel engine operated sprinkler systems. These designs will hold good for areas where peak demand of crop is around 5 mm per day. For other areas, necessary adjustments may be made for farm size and crop water requirement. However, system design procedures will hold good in almost every situation especially for the Barani tract of the Pothwar plateau.

4.2 EFFICIENCY OF PUMPING SYSTEMS

The efficiency of a pumping system depends on number of factors such as the pipe being too small in diameter or having many bends in the conveyance manifold. The most common error is to put the discharge of water considerably above the necessary level. The drive or coupling between pump and prime mover may not be an
efficient unit. Too frequently a pump and prime mover is mismatched so far power requirement is considered. Correct matching of pump, motor/engine and drive is very important for efficient utilization of energy, thus to bring down the irrigation operational cost.

Efficiency will also be reduced by elevation, temperature, accessories, and continuous operation. The details of efficiency estimated for design purpose are as under:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Decrease in Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation from sea level, 3% for each 300 meters, assuming elevation of 450 meters.</td>
<td>4.5</td>
</tr>
<tr>
<td>For each 6° operating air temperature above 16°C, decrease of 1% is encountered; assuming maximum temperature of 45°C.</td>
<td>5.0</td>
</tr>
<tr>
<td>For accessories, using heat exchangers.</td>
<td>5.0</td>
</tr>
<tr>
<td>For continuous load operation</td>
<td>20.0</td>
</tr>
<tr>
<td>Drive losses (0-15 %)</td>
<td>5.0 for motor</td>
</tr>
<tr>
<td></td>
<td>10.0 for engine</td>
</tr>
<tr>
<td>Radiator, fan</td>
<td>5.0</td>
</tr>
</tbody>
</table>

The overall efficiency for pumping systems recommended for sprinkler irrigation is as under.

- Electric motor operated systems = 60 %
- Diesel engine operated systems = 50 %

4.3 DESIGN OF PORTABLE RAINGUN SPRINKLER IRRIGATION SYSTEMS

Eight typical designs are made for sprinkler irrigation systems manufactured in Pakistan mainly considering the size of
diesel engines or tractor power available in the country. However, these designs provide systems for farm size of 2-50 acres. These systems therefore fulfill requirements of small and medium size Barani farmers. Designing of systems for large scale farms require more information about the layout of the farm, crops to be grown, water source and amount, etc. The proposed systems can be used for field crops, vegetables, pulses and young orchards.

4.3.1 SPRINKLER IRRIGATION SYSTEM FOR 2 ACRES FARM

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raingun Type</td>
<td>PY1 20</td>
</tr>
<tr>
<td>Et Peak</td>
<td>5 mm/day</td>
</tr>
<tr>
<td>Peak Operation</td>
<td>10 hours</td>
</tr>
<tr>
<td>Nozzle Size</td>
<td>8 mm</td>
</tr>
<tr>
<td>Working Pressure</td>
<td>4 Kg/cm² = 57 psi = 40 m</td>
</tr>
<tr>
<td>Capacity</td>
<td>4.59 m³/hr = 1.28 lps</td>
</tr>
<tr>
<td>Application</td>
<td>2.86 mm/hr</td>
</tr>
<tr>
<td>Maximum Command Area</td>
<td>0.16 ha = 0.40 acres</td>
</tr>
<tr>
<td>Radius</td>
<td>23 m</td>
</tr>
<tr>
<td>Recommended Farm Size</td>
<td>0.92 ha = 2.3 acres</td>
</tr>
<tr>
<td>Maximum Pipe Length</td>
<td>100 m</td>
</tr>
<tr>
<td>Head Loss in Pipe</td>
<td>1.25 m/100 m in 50 mm (2 inch) diameter pipe</td>
</tr>
<tr>
<td>Total Head</td>
<td>40 + 1.25 + 10 = 51.25 = 25</td>
</tr>
</tbody>
</table>

**POWER REQUIREMENT**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>1.3 lps</td>
</tr>
<tr>
<td>H</td>
<td>52 m</td>
</tr>
<tr>
<td>WPH</td>
<td>0.89 hp</td>
</tr>
</tbody>
</table>

28
Motor HP = 1.5
Engine HP = 1.8

Considering the availability of engines in the market, we need to redesign the system for 3.0 h.p. engines.

\[ Q = 2.0 \text{ lps} \]
\[ H = 57 \text{ m} \]
\[ WPH = 1.5 \text{ hp} \]
Engine HP = 3.0

The height of the sprayline under PY₁-20 raingun sprinkler system is presented in Appendix-I for varying pressure heads and nozzle sizes.

The specifications for raingun and portable trolley mounted pumping system are presented in Figures 1 and 2, respectively. The system can be used for farms of upto 2 acres size to meet peak demand requirement. However, the system can provide irrigation to larger farms if the cropping intensity is less than 200% or irrigation is to be provided to only 2 acres at the farm.

The 50 mm diameter black carbon low-density polyethylene (LDPE) pipe is recommended for delivery and 50-63.5 mm diameter pipe is recommended for suction. The LDPE pipe is equally good for suction and has been successfully tested at the NARC Field Station. The cost of LDPE suction pipe is almost one third of any good quality imported reinforced rubber pipe. Furthermore, the life of black carbon LDPE suction pipe is much more than the reinforced rubber pipe. The cost of the canvas delivery pipe of imported quality is almost same as of LDPE delivery pipe. However, the life of LDPE delivery pipe is much more than canvas pipe.
Figure 1. Schematic view of raingun Sprinkler with connection for LDPE pipe and stand for Model Py1-20 (all Dimensions in inches)
Figure 2. Portable raingun trolley system for 2 acres farm with 3 HP diesel engine (all dimensions in inches)
4.3.2 SPRINKLER IRRIGATION SYSTEM FOR 5 ACRES FARM

Raingun Type = PY1 30
Et Peak = 5 mm/day
Peak Operation = 10 hours
Nozzle Size = 12 mm
Working Pressure = 4 Kg/cm² = 57 psi = 40 m
Capacity = 9.58 m³/hr = 2.74 lps
Application = 3.86 mm/hr
Maximum Command Area= 0.26 ha = 0.64 acres
at One Setting
Radius = 29 m
Recommended Farm Size = 2.0 ha = 5 acres
Maximum Pipe Length = 175 m
Head Loss in Pipe = 5.2 m/100 m in 50 mm (2 inch) diameter pipe
Total Head = 40 + 10 + 9 = 59 meters

POWER REQUIREMENT

\[ Q = 2.8 \text{ lps} \]
\[ H = 59 \text{ m} \]
\[ \text{WPH} = 2.17 \text{ hp} \]
\[ \text{Engine HP} = 4.35 \]

We may redesign the system based on 5 hp engine available in the market.

\[ Q = 3.0 \text{ lps} \]
\[ H = 63 \text{ m} \]
\[ \text{WPH} = 2.5 \text{ hp} \]
\[ \text{Engine HP} = 5.0 \]
For Electric motor system.

\[ Q = 3.0 \text{ lps} \]
\[ H = 60 \text{ m} \]
\[ WPH = 2.4 \text{ hp} \]
\[ \text{Motor HP} = 4.0 \]

The height of the sprayline under PY1-30 raingun sprinkler system is presented in Appendix-II for varying pressure heads and nozzle sizes.

The specifications for raingun and portable trolley mounted pumping system are presented in Figures 3 and 4, respectively. The system can be used to irrigate area of upto 5 acres at the peak demand. The actual farm size may be even more if different crops are grown.

The LDPE black carbon pipe is recommended for delivery and suction purpose.

**4.3.3 SPRINKLER IRRIGATION SYSTEM FOR 10 ACRES FARM**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raingun Type</td>
<td>PY1 40</td>
</tr>
<tr>
<td>Et Peak</td>
<td>5.0 mm/day</td>
</tr>
<tr>
<td>Peak Operation</td>
<td>10 hours</td>
</tr>
<tr>
<td>Nozzle Size</td>
<td>16 mm</td>
</tr>
<tr>
<td>Working Pressure</td>
<td>(4.5 \text{ Kg/cm}^2 = 64 \text{ psi} = 45 \text{ m} )</td>
</tr>
<tr>
<td>Capacity</td>
<td>(19.6 \text{ m}^3/\text{hr} = 5.44 \text{ lps} )</td>
</tr>
<tr>
<td>Application</td>
<td>4.78 mm/hr</td>
</tr>
<tr>
<td>Maximum Command Area at One Setting</td>
<td>0.41 ha = 1.0 acre</td>
</tr>
<tr>
<td>Radius</td>
<td>36 m</td>
</tr>
<tr>
<td>Recommended Farm Size</td>
<td>4.0 ha = 10 acres</td>
</tr>
</tbody>
</table>
Figure 3. Schematic view of rain gun sprinkler with connection for LDPE pipe and stand for Model Py1-30 (all dimensions in inches)
Figure 4. Portable raingun trolley system for 5 acres farm with 5 HP diesel engine (all dimensions in inches)
Maximum Pipe Length = 175 m
Head Loss in Pipe = 2.4 m/100 m for 76 mm (3 inch) diameter pipe
Total Head = 45 + 4.2 + 10 = 60 meters

POWER REQUIREMENT

\[ Q = 5.0 \text{ lps} \]
\[ H = 60.0 \text{ m} \]
\[ \text{WPH} = 4.0 \text{ hp} \]

Engine HP = 8.0 hp

For Electric motor system.

\[ Q = 6.0 \text{ lps} \]
\[ H = 60 \text{ m} \]
\[ \text{WPH} = 4.74 \text{ hp} \]

Motor HP = 8

The height of the sprayline under PY1-40 raingun sprinkler system is presented in Appendix-III for varying pressure heads and nozzle sizes.

The specifications for raingun and portable trolley mounted pumping system are presented in Figures 5 and 6, respectively. The system can be used for farms where area to be irrigated is 10 acres at the peak demand. The actual farm size may be even more

The LDPE black carbon pipe of 76 mm (3 inch) diameter is recommended for delivery and suction purpose.

4.3.4 SPRINKLER IRRIGATION SYSTEM FOR 15 ACRES FARM

Raingun Type = PY1 50
Et Peak = 5.0 mm/day
Peak Operation = 10 hours
Figure 5. Schematic view of raingun sprinkler with connection for LDPE pipe and stand for Model Py₁-40 (all dimensions in inches)
Figure 6. Portable raingun trolley system for 10 acres farm with 8 HP diesel engine (all dimensions in inches)
Nozzle Size = 20 mm
Working Pressure = 5.0 Kg/cm² = 71 psi = 50 m
Capacity = 30.5 m³/hr = 8.5 lps
Application = 5.42 mm/hr
Maximum Command Area at One Setting = 0.56 ha = 1.4 acres
Radius = 42 m
Recommended Farm Size = 6.0 ha = 15 acres
Maximum Pipe Length = 200 m
Head Loss in Pipe = 5.0 m/100 m for 76 mm (3 inch) diameter pipe
Total Head = 50 + 10 + 10 = 70 meters

POWER REQUIREMENT

\[ Q = 8.5 \text{ lps} \]
\[ H = 70.0 \text{ m} \]
\[ WPH = 7.8 \text{ hp} \]

Engine HP = 15.6 or 16 HP
Motor HP = 13 HP

The height of the sprayline under PY₁-50 raingun sprinkler system is presented in Appendix-IV for varying pressure heads and nozzle sizes.

The specifications for raingun and portable trolley mounted pumping system are presented in Figures 7 and 8, respectively. The system can be used for farms where area to be irrigated is 15 acres at the peak demand. The actual farm size may be even more.
Figure 7. Schematic view of raingun sprinkler with connection for LDPE pipe and stand for Model Py₁-50 (all dimensions in inches)
Figure 8. Portable raingun trolley system for 15 acres farm with 16 HP diesel engine (all dimensions in inches)
The LDPE black carbon pipe of 76 mm (3 inch) diameter is recommended for delivery and suction purpose. Which is easy in handling especially for suction purpose.

4.3.5 SPRINKLER IRRIGATION SYSTEM FOR 20 ACRES FARM

Raingun Type = PY₁-60
Et Peak = 5.0 mm/day
Peak Operation = 10 hours
Nozzle Size = 22 mm
Working Pressure = 6 Kg/cm² = 85 psi = 60 m
Capacity = 41.1 m³/hr = 11.4 lps
Application = 5.55 mm/hr
Maximum Command Area = 0.74 ha = 1.83 acres
at One Setting
Radius = 49 m
Maximum Pipe Length = 200 m
Head Loss in Pipe = 2 m/100 m in 102 mm (4 inch) diameter pipe
Total Head = 60 + 4 + 10 = 74 meters
Recommended Farm Size = 8 ha = 20 acres

POWER REQUIREMENT

\[ Q = 12.0 \text{ lps} \]
\[ H = 76 \text{ m} \]
\[ \text{WPH} = 12 \text{ hp} \]
Engine HP = 24 hp
Motor HP = 20 hp

This system is recommended because 24 hp Chinese engines are available in the market. The recommended farm size with 5 mm peak
demand and 10 hours of operation comes to 20.0 acres. The specifications for trolley mounted pumping system are presented in Figure 9.
Figure 9. Portable raingun trolley system for 20 acres farm with 24 HP diesel engine (all dimensions in inches)
The specifications for delivery and suction pipe are similar to other systems. The LDPE black carbon pipe of 102 mm (4 inch) diameter is recommended for delivery and suction purposes.

### 4.3.6 SPRINKLER IRRIGATION SYSTEM FOR 25 ACRES FARM

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raingun Type</td>
<td>PY1-60</td>
</tr>
<tr>
<td>Et Peak</td>
<td>5.0 mm/day</td>
</tr>
<tr>
<td>Peak Operation</td>
<td>10 hours</td>
</tr>
<tr>
<td>Nozzle Size</td>
<td>24 mm</td>
</tr>
<tr>
<td>Working Pressure</td>
<td>6 KG/cm² = 85 psi = 60 m</td>
</tr>
<tr>
<td>Capacity</td>
<td>48.6 m³/hr = 13.5 lps</td>
</tr>
<tr>
<td>Application</td>
<td>5.75 mm/hr</td>
</tr>
<tr>
<td>Maximum Command Area at One Setting</td>
<td>0.85 ha = 2.1 acres</td>
</tr>
<tr>
<td>Radius</td>
<td>52 m</td>
</tr>
<tr>
<td>Maximum Pipe Length</td>
<td>200 m</td>
</tr>
<tr>
<td>Head Loss in Pipe</td>
<td>3.0 m/100 m in 102 mm (4 inch) diameter pipe</td>
</tr>
<tr>
<td>Total Head</td>
<td>60 + 6.0 + 10 = 76 m = 80 m</td>
</tr>
<tr>
<td>Recommended Farm Size</td>
<td>10.0 ha = 25 acres</td>
</tr>
</tbody>
</table>

#### POWER REQUIREMENT

- \( Q = 14.0 \text{ lps} \)
- \( H = 80 \text{ m} \)
- \( \text{WPH} = 14.74 \text{ hp} \)
- \( \text{Engine HP} = 29.47 = 30.0 \text{ hp} \)
- \( \text{Motor HP} = 25.0 \text{ hp} \)

The recommended farm size considering peak demand of 5 mm and 10 hours of operation comes to 25 acres. The 32 hp tractors...
available in the country can be used for this system. The drawing and specifications of the PTO driven trolley mounted pumping system are presented in Figure 10. The LDPE 102 mm (4 inch) diameter is recommended for delivery and suction purposes.

### 4.3.7 SPRINKLER SYSTEM FOR 30 ACRES FARM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raingun Type</td>
<td>PY1-80</td>
</tr>
<tr>
<td>Et Peak</td>
<td>5.0 mm/day</td>
</tr>
<tr>
<td>Peak Operation</td>
<td>10 hours</td>
</tr>
<tr>
<td>Nozzle Size</td>
<td>26 mm</td>
</tr>
<tr>
<td>Working Pressure</td>
<td>7 Kg/cm² = 100 psi = 70 m</td>
</tr>
<tr>
<td>Capacity</td>
<td>60.6 m³/hr = 16.83 lps</td>
</tr>
<tr>
<td>Application</td>
<td>5.86 mm/hr</td>
</tr>
<tr>
<td>Maximum Command Area</td>
<td>1.03 ha = 2.5 acres</td>
</tr>
<tr>
<td>Radius</td>
<td>57 m</td>
</tr>
<tr>
<td>Maximum Pipe Length</td>
<td>200 m</td>
</tr>
<tr>
<td>Head Loss in Pipe</td>
<td>4 m/100 m in 102 mm (4 inch) diameter pipe</td>
</tr>
<tr>
<td>Total Head</td>
<td>70 + 8 + 10 = 90 m</td>
</tr>
<tr>
<td>Recommended Farm Size</td>
<td>12 ha = 30 acres</td>
</tr>
</tbody>
</table>

### POWER REQUIREMENT

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>17.0 lps</td>
</tr>
<tr>
<td>H</td>
<td>90 m</td>
</tr>
<tr>
<td>WPH</td>
<td>20.13 hp</td>
</tr>
<tr>
<td>Engine HP</td>
<td>40.26 = 41 hp</td>
</tr>
</tbody>
</table>

Recommended as PTO driven system with 45 hp or bigger tractors. The farm size recommended with peak demand of 5 mm and 10
Figure 10. PTO driven raingun trolley system for 25 acres farm (all dimensions in inches)
hours of operation comes to 30 acres. The LDPE black carbon pipe is recommended for delivery and suction purposes.

4.3.8 SPRINKLER IRRIGATION SYSTEM FOR 50 ACRES FARM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raingun Type</td>
<td>PY1-80</td>
</tr>
<tr>
<td>Et Peak</td>
<td>5.0 mm/day</td>
</tr>
<tr>
<td>Peak Operation</td>
<td>10 hours</td>
</tr>
<tr>
<td>Nozzle Size</td>
<td>34 mm</td>
</tr>
<tr>
<td>Working Pressure</td>
<td>8 Kg/cm² = 114 psi = 80 m</td>
</tr>
<tr>
<td>Capacity</td>
<td>108 m³/hr = 30 lps</td>
</tr>
<tr>
<td>Application</td>
<td>7.06 mm/hr</td>
</tr>
<tr>
<td>Maximum Command Area at One Setting</td>
<td>1.53 hectares = 3.8 acres</td>
</tr>
<tr>
<td>Radius</td>
<td>70 m</td>
</tr>
<tr>
<td>Maximum Pipe Length</td>
<td>200 m</td>
</tr>
<tr>
<td>Head Loss in Pipe</td>
<td>4.0 m/100 m in 127 mm (5 inch)</td>
</tr>
<tr>
<td>Total Head</td>
<td>80 + 8 + 10 = 98 = 100 m</td>
</tr>
<tr>
<td>Recommended Farm Size</td>
<td>21.0 ha = 50.0 acres</td>
</tr>
</tbody>
</table>

**POWER REQUIREMENT**

\[ Q = 30 \text{ lps} \]
\[ H = 100 \text{ m} \]
\[ WPH = 39.5 \text{ hp} \]
\[ \text{Engine HP} = 79 = 80 \text{ hp} \]

Size of farm recommended considering peak demand of 5 mm and 10 hours of operation comes to 50 acres. The LDPE black carbon pipe...
is recommended for delivery and suction purposes. The PTO driven system with 80 hp tractor can be used for irrigation of 50 acres farm size.
4.4 MANUFACTURING SPECIFICATIONS

4.4.1 ELECTRIC MOTOR OPERATED SYSTEMS

The PARC has already developed production capability with MECO Pvt. Ltd. Lahore to utilize their available facility for manufacturing of mono-black or direct coupled pumping systems for sprinkler irrigation. The manufacturing specifications recommended are:

4.4.1.1 RAINGUN PY, 20 SYSTEM FOR 2 ACRES FARM

The specifications proposed are:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge of pump</td>
<td>1.3 lps</td>
</tr>
<tr>
<td>Pressure Head</td>
<td>52 meters</td>
</tr>
<tr>
<td>Motor Size</td>
<td>1.5 HP</td>
</tr>
<tr>
<td>Delivery Pipe Diameter</td>
<td>50 mm or 2 inch</td>
</tr>
</tbody>
</table>

4.4.1.2 RAINGUN PY, 30 SYSTEM FOR 5 ACRES FARM

The specifications proposed are:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge of pump</td>
<td>3.0 lps</td>
</tr>
<tr>
<td>Pressure Head</td>
<td>60 meters</td>
</tr>
<tr>
<td>Motor Size</td>
<td>4.0 HP</td>
</tr>
<tr>
<td>Delivery Pipe Diameter</td>
<td>50 mm or 2 inch</td>
</tr>
</tbody>
</table>

4.4.1.3 RAINGUN PY, 40 SYSTEM FOR 10 ACRES FARM

The specifications proposed are:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge of pump</td>
<td>6.0 lps</td>
</tr>
<tr>
<td>Pressure Head</td>
<td>60 meters</td>
</tr>
<tr>
<td>Motor Size</td>
<td>8 HP</td>
</tr>
<tr>
<td>Delivery Pipe Diameter</td>
<td>76 mm or 3 inch</td>
</tr>
</tbody>
</table>
4.4.1.4 RAINGUN PY, 50 SYSTEM FOR 15 ACRES FARM

The specifications proposed are:

- Discharge of pump = 8.5 lps
- Pressure Head = 70 meters
- Motor Size = 13 HP
- Delivery Pipe Diameter = 76 mm or 3 inch

4.4.1.5 RAINGUN PY, 60 SYSTEM FOR 20 ACRES FARM

The specifications proposed are:

- Discharge of pump = 12.0 lps
- Pressure Head = 76.0 meters
- Motor Size = 20 HP
- Delivery Pipe Diameter = 102 mm or 4 inch

4.4.1.6 RAINGUN PY, 60 SYSTEM FOR 25 ACRES FARM

The specifications proposed are:

- Discharge of pump = 14 lps
- Pressure Head = 80 meters
- Motor Size = 25 HP
- Delivery Pipe Diameter = 102 mm or 4 inch

4.4.2 DIESEL ENGINE OPERATED SYSTEMS

PARC has designed portable sprinkler irrigation systems using Chinese engine and MECO pumps. The MECO Pvt. Ltd. Lahore is now providing complete units. The detailed specifications of portable sprinkler pumping systems in respect of pump and engine size are:
Diesel operated sprinkler irrigation portable system, multi-stage pump (as per requirement), pressure head and discharge (as per requirement) with desired size chinese engine, installed on an adjustable trolley with 2 wheels and new tyres of 12 inch or desired rim size, 2 stands, towing hook, 6 m LDPE black carbon suction pipe with check valve, coupler at pump outlet with connection for desired size lateral flexible pipe and pressure gauge. All assembly work should be properly aligned, safe and pads should be used at engine and pump foundation to reduce vibrations. All couplings be leak proof. MECO Pvt. Ltd. Kot Lakhpat, Lahore now fabricates these systems.

4.4.2.1 RAINGUN PY₁, 20 SYSTEM FOR 2 ACRES FARM

The specifications proposed are:

- Discharge of pump = 2.0 lps
- Pressure Head = 57 meters
- Engine Size = 3.0 HP
- Delivery Pipe Diameter = 50 mm or 2 inch

4.4.2.2 RAINGUN PY₁, 30 SYSTEM FOR 5 ACRES FARM

The specifications proposed are:

- Discharge of pump = 3.0 lps
- Pressure Head = 63 meters
- Engine Size = 5.0 HP
- Delivery Pipe Diameter = 50 mm or 2 inch

4.4.2.3 RAINGUN PY₁, 40 SYSTEM FOR 10 ACRES FARM

The specifications proposed are:

- Discharge of pump = 5.0 lps
- Pressure Head = 60 meters
- Engine Size = 8 HP
- Delivery Pipe Diameter = 76 mm or 3 inch
4.4.2.4 **RAINGUN PY, 50 SYSTEM FOR 15 ACRES FARM**

The specifications proposed are:

- Discharge of pump = 8.5 lps
- Pressure Head = 70 meters
- Engine Size = 16 HP
- Delivery Pipe Diameter = 76 mm or 3 inch

4.4.3 **TRACTOR PTO DRIVEN SYSTEMS**

When the size of the engine exceeds 16 hp or 24 hp, it is recommended that PTO driven systems may be used because the cost of the pumping systems with engine is very high. Therefore, for farmers who own 25, 32, 45 or 80 hp tractors, the following systems are recommended.

4.4.3.1 **RAINGUN SPRINKLER SYSTEM FOR 20 ACRES FARM**

The specifications proposed are:

- Pump Discharge = 12 lps
- Pressure Head = 76 meters
- Engine Size = 24 hp (use 25 hp tractor PTO)
- Delivery Pipe Diameter = 102 m or 4 inch

4.4.3.2 **RAINGUN SPRINKLER SYSTEM FOR 25 ACRES FARM**

The specifications proposed are:

- Pump Discharge = 14 lps
- Pressure Head = 80 meters
- Engine Size = 30 hp (use 32 hp tractor PTO)
- Delivery Pipe Diameter = 102 m or 4 inch
4.4.3.3 **RAINGUN SPRINKLER SYSTEM FOR 30 ACRES FARM**

The specifications proposed are:

- **Pump Discharge** = 17 lps
- **Pressure Head** = 90 meters
- **Engine Size** = 41 hp (use 45 hp tractor PTO)
- **Delivery Pipe Diameter** = 102 m or 4 inch

4.4.3.4 **RAINGUN SPRINKLER SYSTEM FOR 50 ACRES FARM**

The specifications proposed are:

- **Pump Discharge** = 30 lps
- **Pressure Head** = 100 meters
- **Engine Size** = 80 hp (use 80 hp tractor PTO)
- **Delivery Pipe Diameter** = 102 m or 4 inch

4.5 **SOLID-SET SYSTEMS**

Solid-set systems can be designed considering the following parameters.

- Farm layout
- Farm size and topography
- Crops or plants grown
- Peak water requirement
- Desired overlapping and uniformity efficiency
- Size of prime mover and preference by the farmer
- Sprinkler type
- Pipe specifications and layout
- Pumping systems requirement
- Area to be irrigated per setting
- Labour availability

As the cost of solid-set systems is higher and designing is site-specific, therefore standards designs are not possible. However, LDPE high pressure black carbon pipe or UPVC high pressure pipe can be used for buried lines. The LDPE can also be used for surface installations because LDPE is resistant to ultraviolet rays. The UPVC pipe must be buried in all circumstances.

The topographic and bunded unit maps are the pre-requisite for designing of any solid-set system. The WRRI is trying to develop capability with local companies like Griffon Industrial Corporation, Lahore, Dadex Eternit, Karachi and PVC Shavel, Karachi for the solid-set systems.
Appendix-I. Height of Sprayline for Raingun Model Py1-20

Case-1

<table>
<thead>
<tr>
<th>Distance from the Raingun(m)</th>
<th>Height(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>20</td>
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<td>25</td>
<td>5</td>
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<tr>
<td>30</td>
<td>6</td>
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<tr>
<td>35</td>
<td>7</td>
</tr>
<tr>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td>Max. height = 6.3 m</td>
<td></td>
</tr>
</tbody>
</table>

Nozzle size = 6 mm
Pressure head = 50 psi
Discharge = 0.88 lps
Wind speed = 1.09 km/h
Radius = 22 m

Case-2

<table>
<thead>
<tr>
<th>Distance from the Raingun(m)</th>
<th>Height(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
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<tr>
<td>10</td>
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<td>15</td>
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<tr>
<td>20</td>
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<td>25</td>
<td>5</td>
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<tr>
<td>30</td>
<td>6</td>
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<tr>
<td>35</td>
<td>7</td>
</tr>
<tr>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td>Max. height = 6.9 m</td>
<td></td>
</tr>
</tbody>
</table>

Nozzle size = 6 mm
Pressure head = 60 psi
Discharge = 0.96 lps
Wind speed = 1.09 km/h
Radius = 22 m
**Case-3**

Nozzle size = 6 mm  
Pressure head = 65 psi  
Discharge = 1.01 lps  
Wind speed = 1.09 km/h  
Radius = 24 m

max. height = 7.5 m

**Case-4**

Nozzle size = 6 mm  
Pressure head = 70 psi  
Discharge = 1.23 lps  
Wind speed = 1.09 km/h  
Radius = 26 m

max. height = 7.9 m
Appendix-II. Height of sprayline for Raingun Model Py₁-30

**Case-1**

- Nozzle size: 12 mm
- Pressure head: 60 psi
- Discharge: 2.59 lps
- Wind speed: 0.47 km/h
- Maximum height: 6.0 m

**Case-2**

- Nozzle size: 12 mm
- Pressure head: 60 psi
- Discharge: 3.0 lps
- Wind speed: 0.47 km/h
- Maximum height: 7.1 m
Case-3

- Height (m): 8
- Nozzle size: 12 mm
- Pressure head: 65 psi
- Discharge: 3.14 Ips
- Wind speed: 0.47 km/h
- Radius: 28 m
- Max. height: 7.5 m

Case-4

- Height (m): 10
- Nozzle size: 12 mm
- Pressure head: 70 psi
- Discharge: 3.26 Ips
- Wind speed: 0.47 km/h
- Radius: 31 m
- Max. height: 7.9 m
Appendix-III. Height of Sprayline for Raingun Model Py1-40

Case-1

Height(m)

Distance from the Raingun(m)

max-height=7.8m

Nozzle size=14mm
Pressure head=60 psi
Discharge=2.93 lps
Wind speed=0.65 km/h
Radius=29m

Case-2

Height(m)

Distance from the Raingun(m)

max-height=8.2m

Nozzle size=14 mm
Pressure head=60 psi
Discharge=3.91 lps
Wind speed=0.65 km/h
Radius=31 m
Case-3

Nozzle size=14 mm
Pressure head=65 psi
Discharge=4 lps
Wind speed=0 ~ 5 km/h
Radius=34 m

max. height=8.91 m

Case-4

Nozzle size=14 mm
Pressure head=70 psi
Discharge=4.15 psi
Wind speed=0.65 km/h
Radius=34.2 m

max. height=9.2 m
Case-5

Nozzle size=10 mm
Pressure head=50 psi
Discharge=1.96 lps
Wind speed=0.57 km/h
Radius=27 m

max. height=6.3 m

Case-6

Nozzle size=10 mm
Pressure head=60 psi
Discharge=2.08 lps
Wind speed=0.57 km/h
Radius=28 m

max. height=7.7 m
**Case-7**

- Nozzle size: 10 mm
- Pressure head: 66 psi
- Discharge: 2.21 psi
- Wind speed: 0.57 km/h
- Radius: 31 m

**Max. height:** 8.0 m

---

**Case-8**

- Nozzle size: 10 mm
- Pressure head: 70 psi
- Discharge: 2.3 lps
- Wind speed: 0.67 km/h
- Radius: 34 m

**Max. height:** 8.4 m
Appendix-IV. Height of Sprayline for Raingun Model Py₁-50

Case-1

Height (m)

Distance from the Raingun (m)

Nozzle size = 18 mm
Pressure head = 60 psi
Discharge = 5.36 lps
Wind speed = 1.06 km/h
Radius = 26 m

max. height = 6.0 m

Case-2

Height (m)

Distance from the Raingun (m)

Nozzle size = 18 mm
Pressure head = 60 psi
Wind speed = 1.06 km/h
Discharge = 6.28 lps
Radius = 30 m

max. height = 6.6 m
Case-3

Height (m)

Nozzle size = 18 mm
Pressure head = 65 psi
Discharge = 6.87 lps
Wind speed = 1.06 km/h
Radius = 31 m

max. height = 8.5 m

Case-4

Height (m)

Nozzle size = 18 mm
Pressure head = 70 psi
Discharge = 7.3 lps
Wind speed = 1.06 km/h
Radius = 36 m

max. height = 9.2 m
Appendix-V. Values of the coefficient, $K_F$, for various fittings.

<table>
<thead>
<tr>
<th>Fitting or Valve</th>
<th>76.2</th>
<th>101.6</th>
<th>127</th>
<th>152.4</th>
<th>177.8</th>
<th>203.2</th>
<th>254</th>
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<tbody>
<tr>
<td>Bends:</td>
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</tr>
<tr>
<td>Return flanged</td>
<td>0.33</td>
<td>0.30</td>
<td>0.29</td>
<td>0.28</td>
<td>0.27</td>
<td>0.25</td>
<td>0.24</td>
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<tr>
<td>Return screwed</td>
<td>.80</td>
<td>.70</td>
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<td>Elbows:</td>
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<tr>
<td>Regular Flanged 90°</td>
<td>0.34</td>
<td>0.31</td>
<td>0.30</td>
<td>0.28</td>
<td>0.27</td>
<td>0.26</td>
<td>0.25</td>
</tr>
<tr>
<td>Long radius flanged 90°</td>
<td>.25</td>
<td>.22</td>
<td>.20</td>
<td>.18</td>
<td>.17</td>
<td>.15</td>
<td>.14</td>
</tr>
<tr>
<td>Long radius flanged 45°</td>
<td>.19</td>
<td>.18</td>
<td>.18</td>
<td>.17</td>
<td>.117</td>
<td>.17</td>
<td>.16</td>
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<tr>
<td>Regular screwed 90°</td>
<td>.80</td>
<td>.70</td>
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<tr>
<td>Long radius screwed 90°</td>
<td>.30</td>
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<td>Regular screwed 45°</td>
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<tr>
<td>Flanged line flow</td>
<td>.16</td>
<td>.14</td>
<td>.13</td>
<td>.12</td>
<td>.11</td>
<td>.10</td>
<td>.09</td>
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<td>Flanged branch flow</td>
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<td>.60</td>
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<tr>
<td>Screwed line flow</td>
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<td>.90</td>
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<tr>
<td>Screwed branch line</td>
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<td>Valves:</td>
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<td>Globe flanged</td>
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<td>6.3</td>
<td>6.0</td>
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<td>Globe screwed</td>
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<td>Gate flanged</td>
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<td>Swing check flanged</td>
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<td>Angle flanged</td>
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<tr>
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<td>Foot</td>
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<td>Strainers-basket type</td>
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