Pressurized and Innovative Irrigation Systems: Raingun Sprinkler Systems

S. Ahmad, M. Yasin, G. Akbar, Z. Khan and M.M. Ahmad

INTRODUCTION

Background of skimming wells and pressurized irrigation systems project

Exploitation of groundwater for agricultural, municipal and industrial uses is severely hampered in many parts of the world by the encroachment of brackish groundwater in response to fresh water withdrawals. Examples of brackish groundwater intrusion are common in coastal aquifers, but are sometimes present in inland aquifers as well. Probably, the most important example of the latter case exists in the Indus Basin Irrigation System (IBIS). The IBIS has caused disruption of hydraulic regime due to seepage from extensive water conveyance and distribution system, as well as deep percolation from irrigation and precipitation. The native groundwater that existed in the pre-irrigation period (early 19^{th} century) was saline because of the underlying geologic formation being of marine origin. Now, this native saline groundwater is overlain by fresh groundwater due to seepage from rivers and canals of the IBIS. Thus, shallow fresh groundwater zone occurs between the native pre-irrigation and the present day water tables.

Near the rivers and canals, the fresh surface water seepage has improved the quality of the native groundwater to 120 to 150 m depths. However, in some areas, the thickness of the shallow groundwater zone ranges from less than 60 m along the margins of Doabs (area enclosed between two rivers) to 30 m or less in the lower or central parts of Doabs. Recently, it has been estimated that nearly 200 billion m^3 of fresh groundwater (mostly in the form of a thin layer) is lying on saline groundwater. Obviously, if proper technology is applied, the referred thin fresh groundwater layer can be skimmed from the aquifer with minimum disturbance of the saline groundwater zone. In the short irrigation water supply environment of Pakistan, such extractions would become a significant part of supplemental irrigation.

The explosion of pumping technology in the private sector, high capacity tubewells of more than 28 lps discharge are being installed even in the thin fresh groundwater zones. Framers are normally interested to install tubewells of higher discharges to have efficient basin irrigation by reducing the advance time. This can be regarded as a psychological issue rather than based on techno-economics of tubewells or physical conditions of the aquifer. The discharge of skimming wells might be as low as 3 lps and thus pressurized irrigation technology is necessary for efficient application.

In such zones, these tubewells are likely to draw a substantial portion of their discharge from the saline groundwater. The primary problem is that the tubewell discharges are too large for the given physical situation of the aquifer. This is particularly true for the tubewells located in the central regions of Doabs in Punjab province of Pakistan. The exception would be tubewells located adjacent to rivers and large canals where large quantities of seepage are recharging the groundwater reservoir.

Thus, if such tubewells are not replaced with fractional skimming wells, there is a serious concern that the pumped groundwater will become increasingly saline with time. Already, many high capacity public tubewells are being shutdown at the request of farmers in these areas, as the pumped water has become saline with time. In addition, there is a high expectation that many private tubewells will have to be abandoned during the next coming years. Therefore, it is imperative to introduce fractional skimming well and pressurized irrigation technology to address these future concerns.

Taking into consideration the vital importance and urgent need for developing fractional skimming wells and pressurized irrigation technology, a tripartite institutional arrangement Water Resources Research Institute (WRRI), National Agricultural Research Centre (NARC); Mona Reclamation Experimental Project (MREP), Bhalwal; and the International Water Management Institute (IWMI) was developed to initiate a collaborative project entitled "Root-Zone Salinity Management using Skimming Wells through Pressurized Irrigation Systems". The project was financed by WAPDA under the National Drainage Program (NDP) and initiated in the Target Area at the Mona Reclamation Experimental Project, Bhalwal during November 1998.

Objectives of the project component

The project objectives are to:

1. Identify and test limited number of promising technologies of fractional skimming well in the shallow fresh groundwater aquifers, which could control the saline groundwater up-coning phenomenon as a consequence of pumping;
2. Encourage and support in-country manufacturers to develop low-cost pressurized irrigation application systems adaptable within the local setting of Pakistan; and
3. Prepare and implement guidelines for irrigation scheduling with skimmed groundwater applied by low-cost pressurized irrigation systems to manage root zone salinity

Based on the project objectives, the WRRI was assigned to conduct research on skimming dugwells and pressurized irrigation systems. After finalizing the methodological studies, the dugwell and Raingun sprinkler irrigation study was conducted initially at the Phularwan Experimental Farm of the MREP, Bhalwal. The activities initiated were:

- Renovation of the existing skimming dugwell located at the Phularwan Farm and installation of the electric and diesel powered prime movers;
- Hydraulics of the skimming dugwell;
- Design and layout of the Raingun sprinkler irrigation system and hydraulics study; and
- Conceptual framework for design and operation of irrigation systems.

SPRINKLER IRRIGATION SYSTEMS

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 input 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

Advantages of sprinkler irrigation

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.

Stream size required for sprinkler irrigation is much less as compared to the surface irrigation. The locally manufactured Raingun Sprinkler Systems can be used with discharge of even less than 3 lps, whereas atleast 14 lps are required for surface irrigation to a field size of around 0.26 ha. Therefore, smaller discharges of dugwells can be applied efficiently using sprinkler irrigation. Furthermore, application of net irrigation is possible even to replenish one-day requirement of 1-5 mm in contrast to surface irrigation where atleast 75 mm are required to cover the field. Even in surface irrigation, it is not possible to apply 75 mm at the time of first irrigation where the land is tilled and infiltration is higher. The advance time for the first irrigation is quite large compared to the subsequent irrigations.

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 permeability. In areas where labour and water costs are high, sprinklers can be the most economical way to apply water. In many cases, sprinklers have shown increase in yield, such as in the fresh vegetables and fruits where colour and quality are very important.

One of the advantages of sprinkler irrigation is to attain higher uniformity in leaching of salts even with light irrigation. In the imperial Valley of California on a silt-loam soil, a depth of 1100 mm of water was required for continuous flooding to achieve the same degree of reclamation as did 720 mm applied intermittently (Oster et al., 1972). In Israel and sometime in the US, leaching is done by sprinkling. The advantage of sprinkler irrigation over flooding is that water can be applied at a rate less than the soil infiltration rate, thereby avoiding ponding. In a field experiment on a silt-clay soil classified as moderately alkali and high in salts, Nielsen et al. (1965) found that 260 mm of water applied intermittently by sprinkling reduced the salt contents of the upper 0.6 m of the profile to the same degree as 750 mm applied by continuous flooding. This shows that water required for reclamation was reduced to one-third with sprinkler irrigation compared to the surface irrigation.

Sprinklers often have multiple uses. The same equipment can be used for irrigation, crop cooling, 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 to 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.

Disadvantages of sprinkler irrigation

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.

PIPELINE HYDRAULICS AND DESIGN EQUATIONS FOR SPRINKLER IRRIGATION SYSTEMS

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 efficiency and uniformity will be high.

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:

$$h_f = \left\{ K \left(\frac{Q}{C} \right)^{1.852} \right\} * \left(\frac{L}{D} \right)^{4.87} \qquad (1)$$

in which,

K	=	1.21 x 1010;
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
h_f	=	Frictional head loss, m.

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

$$h_f = f\left\{\frac{(LV^2)}{(D*2g)}\right\} \qquad (2)$$

Where,

L	=	Pipe length, m;
D	=	Pipe diameter, m
V	=	Average flow velocity, m/sec;
g	=	Gravitational constant, 9.81 m/sec^2; and
f	=	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:

$$R_e = 1.26*10^6*\left(\frac{Q}{D}\right) \qquad (3)$$

in which;

R_e	=	Reynolds Number;
Q	=	Pipe discharge, lps; and
D	=	Inside pipe diameter, mm.

Then the value of f is determined as follows:

f	=	$(64/R_e)$	for $R_e < 2100$	(4)
f	=	0.04	$2100 < R_e < 3000$	(5)
f	=	$(0.32/R_e^{0.25})$	$3000 < R_e < 105$	(6)
f	=	$(0.13/R_e^{0.172})$	$105 < R_e < 107$	(7)

Substitution of Eqns. 4, 5, 6 and 7 into (2) resulted into simplified expression.

$$h_f = (A_i * Q^{mi} * L)/D^{Pi} \qquad (8)$$

The values of I, Ai, Pi and R are presented in Table 1.

$$m_i = P_i - 3 \qquad (9)$$

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:

$$h_F = K_F(V^2/2g) \qquad (10)$$

The values of K_F are presented in Annex. I.

Table 1. **Values of I, Ai, Pi and R.**

I	Ai	Pi	R
1	4.1969*103	4.0	Re < 2100
2	3.3051*106	5.0	2100 < Re < 3000
3	7.8918*105	4.75	3000 < Re < 105
4	9.5896*105	4.828	105 < Re < 107
C=140 for Hazen W.	1.283x106	4.852	105 < Re < 107

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:

$$F = (1/m+1) + (1/2N) + \{(m-1)^{0.5}/(6N^2)\} \quad (11)$$

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_i = 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.

$$F' = \{2N/(2N-1)\} * F - \{1/(2N-1)\} \quad (12)$$

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'.

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.

$$QL = \{(N - (L/S_s)\} * q \quad (13)$$

$$L = N * S_s \quad (14)$$

$$QL = \{(q/S_s)*(L - L')\} \quad (15)$$

in which,

QL = 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.

$$H_L = H_1 - R_L h_f + \{(Z_1 - Z_2)*(L'/L)\} \quad (16)$$

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' = any point distance from inlet, and

h_f = total headloss in pipe.

$$Hf = \{(aL * aL^{Pi-2})/(P_i-2)\} \quad (17)$$

$$a = \{Ai * (q/S_s)^{Pi-3}\}/(D^{Pi}) \quad (18)$$

$$R_L = 1 - \{(L-L')/L\}^{Pi-2} \quad (19)$$

Friction loss in pipes 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.

$$L = L_L + L_s \quad (20)$$

$$N_L = L_L/(S_s) \quad (21)$$

$$N_s = L_s/S_s \quad (22)$$

The procedure for calculating the headloss utilizes equations (2) and (12) as follows:

a) Calculate the headloss for the flow in the smaller pipe:

$$(h_f)_s = h_f\,(Ds, Qs, Ls).\ F\,(Ns, m) \quad (23)$$

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

$$(h_f)_{L'} = h_f * \{(D_L, Q_s, L_s)\} * \{F^*(N_s, m)\} \quad (24)$$

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

$$(h_f)_L = h_f\{(D_L, Q, L)\} * \{F * (N, m)\} \quad (25)$$

d) Then, the total pressure headloss is:

$$h_f = (h_f)_s - (h_f)_{L'} + (h_f)_L \quad (26)$$

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:

$$Da = f *(TAW)/Ea \quad (27)$$

Where

Da = gross average water application, mm;

f = allowable soil moisture depletion expressed as a fraction;

TAW = total available soil moisture in the root zone, mm; and

Ea = application efficiency expressed as a fraction.

The frequency with which this depth must be applied is:

$$I_i = f. * TAW/(E_t) \quad (28)$$

in which

Ii = irrigation interval in days; and

E_t = design E_t rate, mm/day.

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

$$D = \{(Da * N') /(I_i * T_d)\} = \{(N' * E_t)/(E_a * T_d)\} \quad (29)$$

Where

D = average application rate, mm/hr;

N' = number of sets per irrigation; and

T_d = number of hours per day the system operates.

The Kostiakov infiltration function is described as:

$$Z = a T^b \quad (30)$$

Where

Z = cumulative infiltration, mm;

T = hours since infiltration begins; and

a,b = empirical functions

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

$$N_s = Q_L/q_s \quad (31)$$

Where

Q_L = discharge of manifold or lateral line, lps;

q_s = sprinkler discharge, lps; and

N_s = number of sprinklers.

APPLICATION AND DESIGN OF RAINGUN SPRINKLER IRRIGATION SYSTEMS

Sprinkler irrigation in Pakistan

Sprinkler irrigation is being introduced 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 Northern Areas, NWFP and Balochistan. Furthermore, these systems are suitable for areas where streamsize is very small and surface irrigation is not possible. Such locations are available in areas having limited well yields in mountainous and Barani regions and in the Indus basin having very thin layer of fresh groundwater.

The sprinkler irrigation system can be easily introduced for high value vegetables and fruits in areas where either value of water is high or problem soils. 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 2.

Table 2. Recommended low-cost Chinese raingun sprinkler systems for various physical and socio-economic conditions in Pakistan.

Farm Size (ha)	Raingun Model	Working Pressure (m)	Prime Mover	Area Coverage per Setting (ha)
1	Py1-20	40	Electric/Diesel	0.16
2	Py1-30*	40	Electric/Diesel	0.26
4	Py1-40	45	Electric/Diesel	0.40
6	Py1-50*	50	Electric/Diesel	0.56
8	Py1-60	60	Electric/Diesel	0.73
10	Py1-60	60	Electric/Diesel/PTO	0.84
12	Py1-80	70	PTO Driven	1.00
20	Py-80	80	PTO Driven	1.52

* Locally manufactured models in Pakistan.

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 Water Resources Research Institute of the, National Agricultural Research Centre, 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 now available in 13,. 25, 50, 75 and 100 mm diameter which can be used for pressures upto 84 m. In the near future, other low pressure systems will also be developed. The estimated installed cost of portable raingun sprinkler system is in the range of Rs. 15000-25000 per ha for a system of atleast 4 ha using diesel operated pumping system. The cost of electric operated systems is in the range of Rs. 10,000-20,000 per ha for a system of 2 ha or more.

Application of raingun sprinkler systems

Barani Areas

The Raingun sprinkler irrigation system was initially designed to provide irrigation in areas where surface irrigation was either not possible or huge investments were 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 unlevelled 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 was 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. The streamsize is normally small between 3-7 lps in most of the areas. 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 deigned command area of small and mini dams, respectively, have been developed for surface 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 these 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 optimise farmers' net return in Barani areas.

Indus basin irrigated agriculture

The Raingun Sprinkler systems can also be used in the Indus basin for efficient application of smaller streamsize of even less than 3 lps pumped from the skimming wells. However, to minimise the input of groundwater and to maintain low cost of irrigation, it is necessary to integrate conjunctive use of rainfall, surface water and groundwater. The design and operation of irrigation systems will be based on the concept of management strategies considering the conjunctive water use.

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. 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 given in Table 3.

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

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

The actual efficiency of locally made Chinese diesel engines based pumping systems ranges between 25-40% compared to the recommended of 50% based on the testing made by the WRRI-NARC. Similarly, the low cost electric motor based pumping systems' efficiency ranges between 30-50% compared to the recommended efficiency of 60%. The energy efficient pimping systems are costly and beyond the reach of Pakistani farmers. These pumps with electric motors can provide efficiency of even up to 84%. The Jack pump being indigenized by the local industry in collaboration with the WRRI-NARC is the most efficient pump in the world. However, in future there will be much awareness and demand for having energy efficient pumping systems with the increase of electricity terrif and increase in fuel prices.

Table 3. Elements causes decrease in efficiency of pumping systems

Parameters	Decrease in Efficiency (%)
Elevation from sea level, 1% for each 100 meters, assuming elevation of 200 meters.	2.0
For each 6° operating air temperature above 16°C, decrease of 1% is encountered; assuming maximum temperature of 45°C.	5.0
For accessories, using heat exchangers.	5.0
For continuous load operation	20.0
Drive losses (0-15 %) for motor	5.0
Drive losses (0-15 %) for engine	10.0
Radiator Fan	5.0

Design of portable raingun sprinkler irrigation system

Sprinkler irrigation system for 2 ha farm size

Raingun Type = PY1 30

Et Peak = 5 mm/day

Peak Operation = 10 hours

Nozzle Size = 12 mm

Working Pressure = 4 Kg/cm^2 = 57 psi = 40 m

Capacity	=	9.58 m^3/hr	=	2.74 lps
Application	=	3.86 mm/hr		
Maximum Command Area at One Setting	=	0.26 ha		
Radius	=	29 m		
Recommended Farm Size	=	2.0 ha		
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

For diesel engine operated system

Q	=	2.8 lps
H	=	59 m
WPH	=	2.2 hp
Engine HP	=	4.4

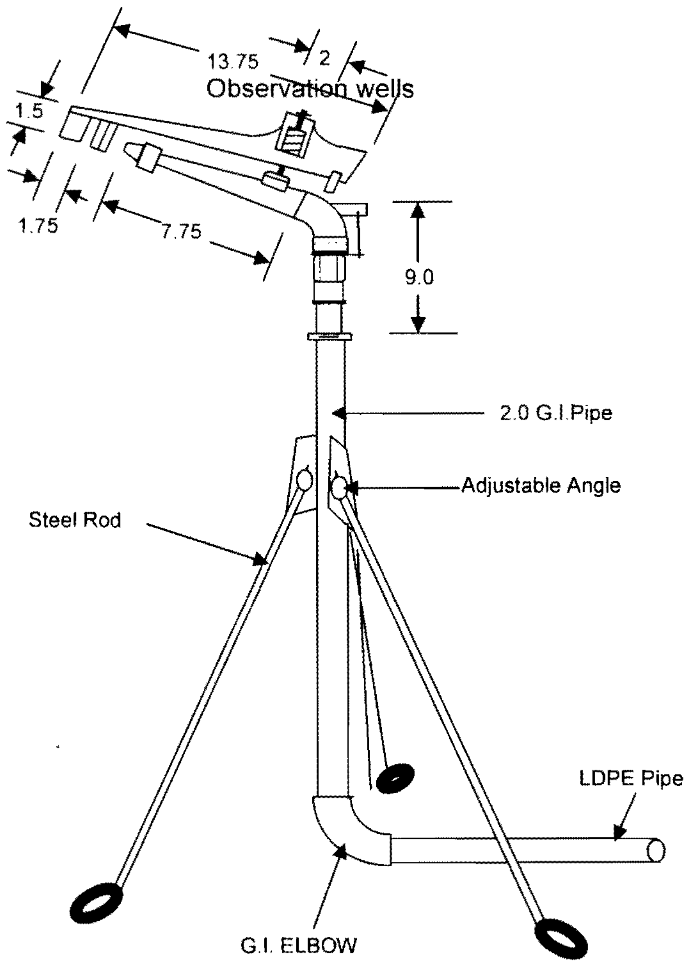
We may redesign the system based on 5 to 8 hp engines available in the market.

Q	=	3.0 lps
H	=	60 m
WPH	=	2.5 hp
Engine HP	=	5.0 to 8

For Electric Motor Operated System.

Q	=	3.0 lps
H	=	60 m
WPH	=	2.4 hp
Motor HP	=	4.0 to 5

The height of the sprayline under Py1-30 raingun sprinkler system is presented in Annex. II 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 to irrigate area of up to 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.

Figure 1. Schematic diagram of the raingun (Py1-30) (dimensions in mm)

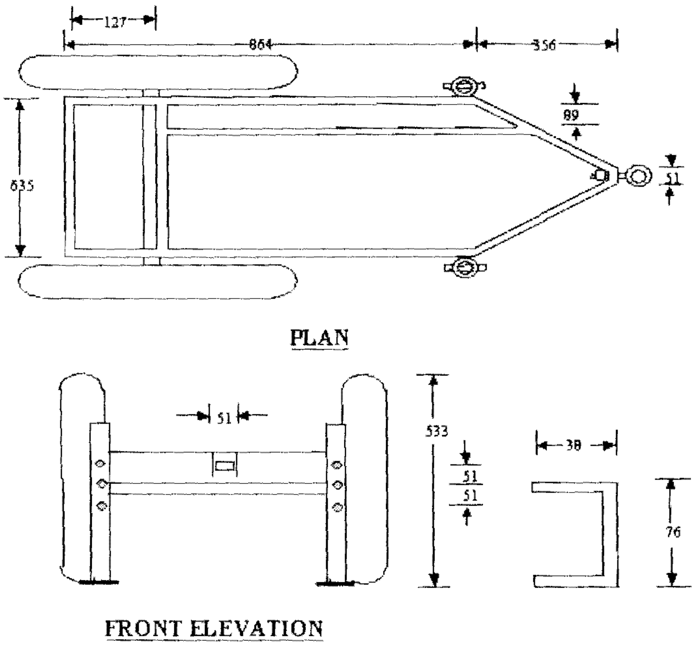


Figure 2. **Portable trolley mounted Raingun (Py1-30) sprinkler irrigation systems (dimensions in mm).**

Manufacturing specifications of raingun sprinklers

Electric motor operated systems

The WRRI-NARC 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:

Raingun Py1-30 system for 2 ha farm size

The specifications proposed are:

Discharge of pump	=	3.0 lps
Pressure Head	=	60 meters
Motor Size	=	4.0 to 5.0 HP
Delivery Pipe Diameter	=	50 mm or 2 inch

Diesel engine operated systems

WRRI-NARC 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.

Raingun Py1- 30 System for 2 ha Farm Size

The specifications proposed are:

Discharge of pump	=	3.0 lps
Pressure Head	=	60 meters
Engine Size	=	5.0 to 8.0 HP
Delivery Pipe Diameter	=	50 mm or 2 inch

Layout of skimming dugwell and field experimental area

The NDP financed project entitled "Root Zone Salinity Management using Fractional Skimming Wells with Pressurized Irrigation" was implemented initially at the Mona Reclamation Experimental Project, Bhalwal, Sargodha, Pakistan. The potential project sites and interventions in the farmers' fields had to be selected after conducting reconnaissance surveys, GIS study of deep groundwater of SCARP tubewells in the Mona project, participatory rural appraisals and diagnostic analysis study. Therefore, it was decided to conduct the initial field experimentation at the Phularwan Farm of the Mona Reclamation Experimental Project, Bhalwal.

The existing dugwell is located at the North corner of the Phularwan Farm. The layout of the farm and position of the dugwell is presented in Figure 3. It was an abandoned dugwell and filled with soil and other waste materials. Therefore, it was cleaned and renovated. The renovation also included some of the masonry work and plastering of walls and roof of the well above ground surface. The diameter of the well is around 3 m while depth of the well is 6.25 m from the ground surface. The maximum depth of water column was around 5 m. The schematic diagram of the dugwell is presented at Figure 4.

Installation of pumping systems

An electric motor of 5 hp and a diesel engine of 8 hp were installed on the wooden platform of the dugwell. The suction line was connected both with diesel and electric pumping systems. These pumping systems were installed in such a way that each of the system could be operated independently. The diesel pumping system was installed so that data could be collected even during breakdown of electricity and thus reliability of the irrigation system could be improved. Furthermore, most of the farmers are interested in diesel operated systems rather the PRA indicated that 100 % tubewells in the selected 13 villages were powered with diesel engines primarily due to the higher electricity terrif.

Layout of raingun sprinkler irrigation system

A 50 mm diameter polyethylene pipe was laid out at a depth of about 60 cm from the ground surface. Then it was covered with soil for its protection. The mainline was laid along the boundary of the two adjoining fields. The risers were installed in the centre of the fields to have facility for irrigation of each and every field. The length of the mainline was 200m and can irrigate three fields on either side. The size of the field is 33m x 66m.

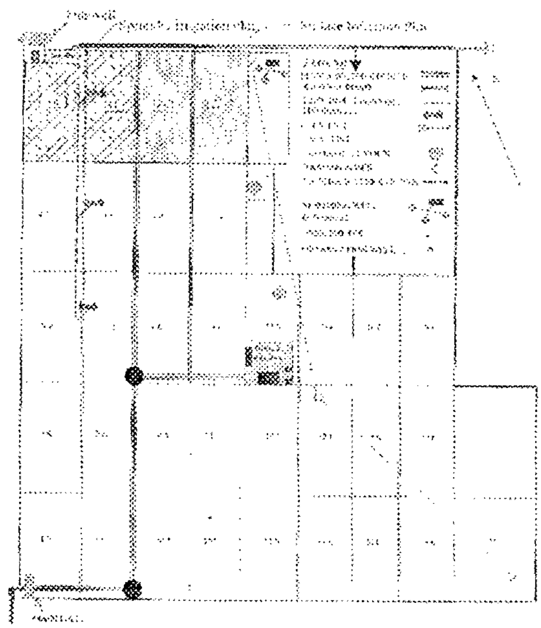
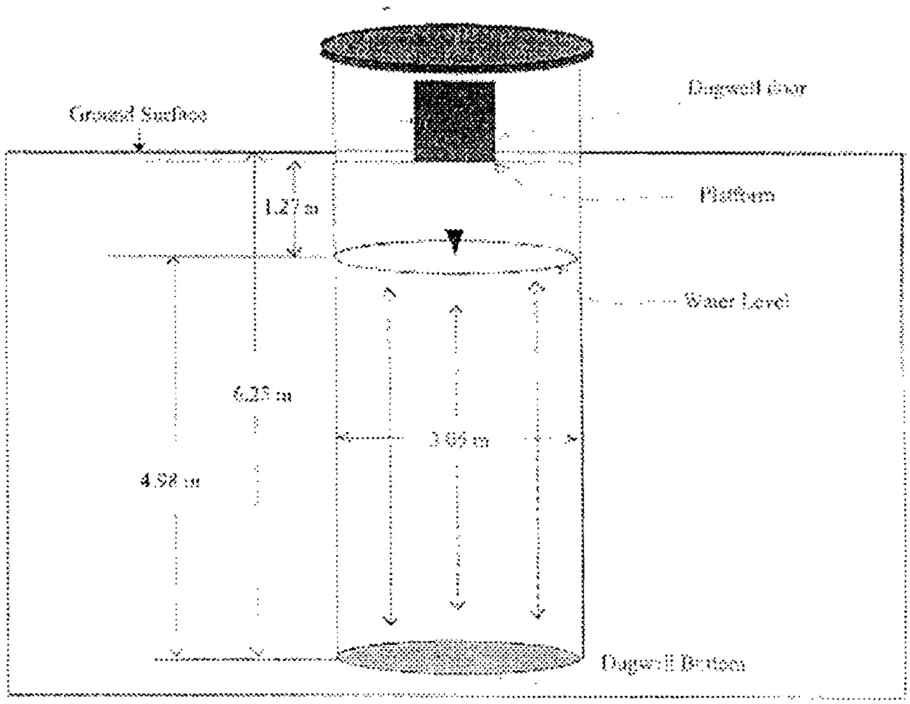


Figure 3. Layout of Phullarwan Farm and position of dugwell.



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Findings of Initial Field Experimentation

Discharge of raingun sprinkler

A water meter was installed on the mainline of the Raingun (Py1-30) sprinkler irrigation system at the skimming dugwell. The water meter reading was recorded before operating the Raingun sprinkler irrigation system. Later on, the water meter readings were recorded after an interval of 30 minutes. The difference in readings gave volume of water passed in 30 minutes interval. The volume of water pumped per unit of time gave discharge of the skimming dugwell. The depth of water depleted in the dugwell, and discharge and pressure of Raingun system as a function of time were estimated.

The discharge of Raingun sprinkler decreased with time due to the increase in suction head. The discharge received during the first 30 minutes of operation of the Raingun sprinkler ranged from 2.93 lps to 2.53 lps during the period of five months (Table 4). The Raingun discharge was reduced to around 2 lps after 4.5 to 5 hours of pumping. Thus Raingun (Py1-30) sprinkler can be operated for 4.5 to 5 hours with discharge range of 2 to 3 lps.

Table 4. Discharge of Raingun (Py_1 - 30) sprinkler irrigation system using the skimming dugwell at the Phularwan Farm, MREP, Bhalwal.

Time (hrs)	Discharge of Raingun Sprinkler Irrigation System (lps)						
	Aug. 1999	Sep. 1999	Oct. 1999	Nov. 1999	Jan. 2000	Feb. 2000	Mar. 2000
0.5	2.93	2.76	2.53	2.74	2.73	2.61	2.57
1.0	2.74	2.76	2.53	2.43	2.67	2.57	2.63
1.5	2.61	2.69	2.50	2.43	2.61	2.51	2.44
2.0	2.46	2.60	2.94	2.31	2.52	2.50	2.56
2.5	2.32	2.47	1.69	2.33	2.39	2.34	2.35
3.0	2.20	2.36	2.17	2.32	2.33	2.22	2.36
3.5	2.01	2.30	2.11	2.02	2.26	2.17	1.96
4.0	2.00	2.24	2.01	1.86	2.13	2.16	2.11
4.5	1.97	2.18	1.98	1.88	2.09	2.05	2.19
5.0	1.92	2.29	1.80	1.83	2.01	1.98	1.70

Pressure of raingun sprinkler

Pressure gauge was installed on the mainline of the Raingun sprinkler irrigation system installed at the Phularwan Farm, Bhalwal. The gauge readings were recorded after an interval of 30 minutes until the system was stopped due to either completion of irrigation or lowering of water level in the dugwell.

The depth of water depleted in the dugwell, and discharge and pressure of Raingun sprinkler as a function of time were determined. The time interval of 30 minutes was kept during the operation of the Raingun. The purpose was to establish relationship between pressure and discharge of Raingun sprinklers as a function of time and depth of water level in the skimming dugwell.

The pressure decreased with the increase in suction lift of the pumping system. The pressure measured after an interval of 30 minutes ranged from 41 to 47 psi (Table 5). After pumping operation of 4 hours, the pressure ranged from 26 to 31 psi. After 5 hours of pumping operation of the Raingun, the pressure ranged from 18 to 26 psi. It means that the Raingun (Py1-30) can be operated for 4-5 hrs duration with a pressure range of 18 to 46 psi. The decrease in pressure with time was due to the increase in the suction head.

Pressure and discharge functions of raingun sprinkler system

The depth of water level depleted, pressure and discharge of Raingun as a function of time were measured at 30 minutes interval at the skimming dugwell, Phularwan Farm (Table 6). After 5 hours of operation of the Raingun, the depth of water level depleted, and pressure and discharge of Raingun sprinkler were 3.8 m, 25.7 psi and 1.93 lps, respectively.

The Ringun sprinkler pressure and discharge were reduced with the increase in suction head (Figure 5 and 6). The sudden decrease in discharge was observed with the decrease in pressure beyond 37 psi. At this pressure, the depth of water level depleted was about 2m. The pressure of Raingun sprinkler was decreased with the increase in depletion of the depth of water level. Depletion of 2m depth of water level in the dugwell occurred after about 2 hours of operation of Raingun sprinklers. The discharge of around 2.5 lps was available at this depth of water level. The relationship between pressure and discharge of Raingun sprinkler at the skimming dugwell is presented in Figure 7.

Table 5. **Pressure of Raingun (Py_1 - 30) sprinkler irrigation system as a function of time at the Phularwan Farm, MREP, Bhalwal.**

Time (hrs)	Pressure of Raingun Sprinkler Irrigation System (psi)						
	Aug. 1999	Sep. 1999	Oct. 1999	Nov. 1999	Jan. 2000	Feb. 2000	Mar. 2000
0.5		46.0	41.0	41	47	44	43
1.0		44.0	37.0	39	45	42	40
1.5		41.0	36.0	37	43	39	38
2.0		39.0	36.0	35	40	37	36
2.5		35.0	35.0	32	37	34	34
3.0		33.0	32.0	30	35	33	31
3.5		30.0	29.0	28	33	30	29
4.0		28.0	26.0	26	31	28	27
4.5		26.5	20.5	25	29	26	24
5.0		24.0	18.0	23	26	24	22

Table 6. **Depth of water depleted, pressure and discharge of Raingun (Py_1 - 30) sprinkler irrigation system at the Phularwan Farm, MREP, Bhalwal.**

Time (hrs)	Depth Depleted (m)	Pressure (psi)	Discharge (lps)
0.5	0.59	43.57	2.70
1.0	1.12	41.29	2.62
1.5	1.59	39.00	2.54
2.0	2.03	36.93	2.56
2.5	2.40	37.00	2.27
3.0	2.76	34.86	2.28
3.5	3.07	32.36	2.12
4.0	3.33	30.43	2.07
4.5	3.57	28.00	2.05
5.0	3.80	25.71	1.93

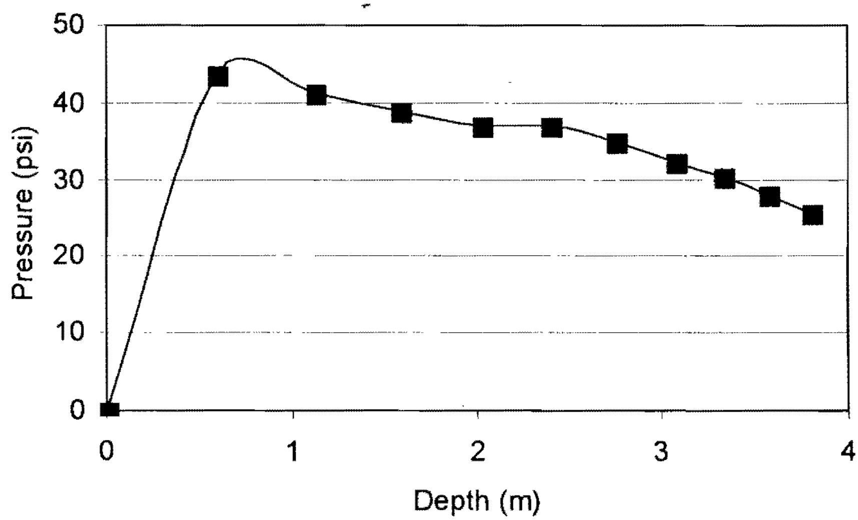

Figure 5. Relationship between depth depleted in the skimming dugwell and pressure of the Raingun at Phularwan Farm, MREP, Bhalwal.

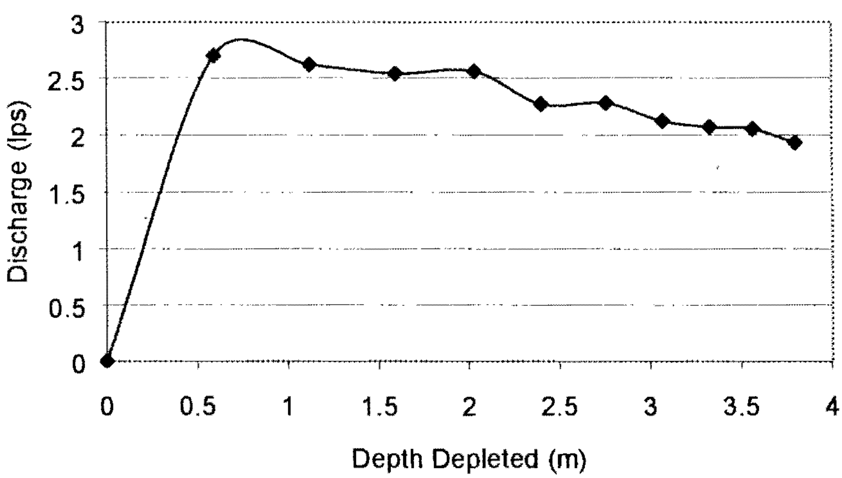

Figure 6. Relationship between depth depleted in the skimming dugwell and discharge of the Raingun at Phularwan Farm, MREP, Bhalwal.

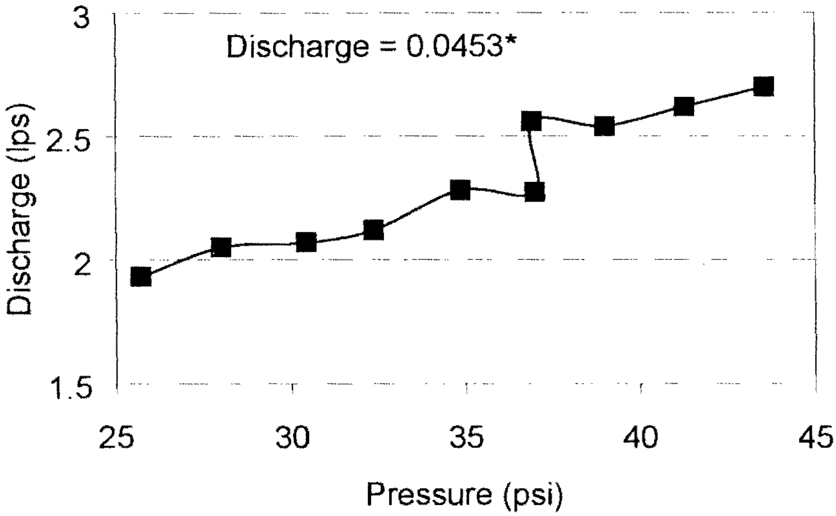

Figure 7. Relationship of discharge and pressure of Raingun (Py1-30) Sprinkler System used at Skimming Dugwell Phularwan Farm, MREP, Bhalwal.

Volume of water pumped by the raingun sprinkler system

While the Raingun sprinkler irrigation system was operated, the depletion of depth of groundwater in the skimming dugwell was measured after an interval of 30 minutes. The depth of water level depleted was multiplied by cross-sectional area of the well to determine volume of water pumped from the well. Thus the quantity of water pumped was determined at different depths of the water level in the skimming dugwell for different time duration. The volume of water pumped at different depths of water level depleted is presented in Table 7. The quantity of water pumped was increased with the increase in depletion of the depth of water level. After 4 hours of operation of the Raingun, a depth of 3.33 m was depleted in the skimming dugwell while 24.32 m^3 volume of water was pumped for irrigation.

Table 7. **Relationship between volume of water pumped and depth of water level depleted using Raingun (Py_1 - 30) Sprinkler irrigation system at the Phularwan Farm, MREP, Bhalwal.**

Time (hrs)	Depth of Water Level Depleted in the Skimming Dugwell (m)	Volume of Water Pumped (m^3)
0.5	0.59	4.31
1.0	1.12	8.18
1.5	1.59	11.61
2.0	2.03	14.82
2.5	2.40	17.53
3.0	2.76	20.15
3.5	3.07	22.42
4.0	3.33	24.32
4.5	3.57	26.07
5.0	3.80	27.75

CONCEPTUAL FRAMEWORK FOR DESIGN AND OPERATIONOF IRRIGATION APPLICATION SYSTEMS

The essential elements of the conceptual framework for design and operation of irrigation systems are as under:

- Design of pressurized irrigation system should be based on the concept of supplemental irrigation where objective would be to minimize the input of groundwater to maintain the profitability of irrigated agriculture. The first most important problem encountered by the farmer is the profitability of irrigated agriculture. The cost of tubewell irrigation is many-fold higher than the canal irrigation. Therefore, the groundwater based pressurized irrigation must be designed to reduce the operational cost of well irrigation. Therefore, the pressurized irrigation systems have to be seen in the context of complementing the existing canal irrigation systems.
- Alongwith irrigation priority based on modified MAD, an economic priority should be assigned to various crops considering the value of the marketable product. Farmers are practicing this strategy especially for the canal irrigation where a different priority is assigned to cereals, fodder and orchards.
- Conjunctive water use should be a part of the irrigation scheduling framework where rainfall, surface water and groundwater must be

considered. Irrigation scheduling criteria should be based on modified MAD, which helps to maximize the use of rainfall and canal water in order of priority, respectively. Groundwater use should be made when canal water is not available.

- Dmin and Dmax limits for irrigation has to be defined both for canal irrigation and pressurized irrigation systems. The strategy of deficit irrigation helps to maximize the use of rainfall, whereas allowance has to be made for the quality of groundwater in terms of leaching fraction.
- Sprinkler irrigation systems can also be used for other activities like crop cooling, frost control and foliar application of fertilizers and chemicals. Therefore, irrigation scheduling framework should consider fertigation concept instead of irrigation only.
- The use of drip irrigation should be limited to orchards to keep the cost low. It is not economical to use drip irrigation for row crops and fodders.

The IWMI is involved in preparing the framework for irrigation scheduling for pressurized irrigation. The above mentioned points should be considered while finalizing the framework.

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