Hydraulic design and performance evaluation of landscape irrigation systems

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Abstract: Landscape irrigation systems serve the purpose of lifeline for urban agriculture and horticulture activities such as golf courses, theme parks, airport turfing, traffic islands, surface and rooftop gardening in commercial complexes. A Landscape irrigation system is essentially a pressure irrigation system comprising pop up sprinklers, micro sprinklers and hydrants. The hydraulics involved is very complex due to undulating nature of landscapes. The performance of the pop-up sprinkler used in irrigation of landscaping project (University Auditorium, TNAU) was evaluated. The main analysis examined the relationship between flow-pressure, profile of distribution of water and Christiansen's Uniformity Coefficient (CUC) related with flow pressure. The value of CUC was observed more than 94 percent.

Keywords: Landscape development, Pop-up sprinklers- Friction loss, Uniformity Co-efficient.

Landscape development warrants an _nterrupted and uninterrupted application of water o provide for improved human use of land, esthetic enjoyment and positive influence on he environment of community. In this era of ncreased plastic usage and pollution, living lants are essential to sustain the nature's cycle f oxygen replenishment for our atmosphere. Landscape irrigation complements to this purpose y the way of creating a lush, pasture or hrubby mosaic of greenery in parks, gardens, otels, resorts, conference center, temples, ommercial, residential complexes and golf courses. Landscape irrigation system needs to be designed vith special care because of man - made obstacles vhich are not encountered in agricultural irrigation ystem design. The main obstacles forming a art and parcel of the irrigation layout are he artificially created uneven slopes, mounts, tc. The selection of irrigation equipment, mostly prinklers, should be in such a way that no vater should spray outside the landscape which vay affect the pedestrian and at the same time esthetics should be restored. It is a tailor nade irrigation system to suit the conditions of particular landscape area. In the context of Landscape Irrigation layout, manual watering s found to be very insufficient in the application of moisture and the huge labour cost prohibits he use of the method in many parts of the country. The daytime operation is bound to ncrease the loss of moisture due to evaporation and may not be practical method in regions where water-rationing restrictions do not allow andscape irrigation in the afternoon and evening hours. Automatic Irrigation system offers many advantages including savings in the cost of labour. However the hydraulic design, layout and perforimnce evaluation of landscape irrigation system is complex due to its inherent location specific nature. Most economical landscape irrigation system using pop-up sprinklers was designed and laid out in the premises of Tamil Nadu Agricultural University, and their performance was evaluated. This paper describes the relationship between flow-pressure, profile of distribution of water and Christiansen's Uniformity Coefficient (CUC) related with flow pressure.

Design criteria

In Landscape irrigation systems mostly pop-up sprinkler heads are used instead of overhead sprinklers to improve upon the aesthetic value of the area. These sprinklers are installed below ground level, a portion of sprinkler rises out from the ground when the sprinkler is operating and then retracts back below ground when not in use. Further pop-up sprinkler heads are divided into two types based on the method they are used to distribute the water.

Pop-up Spray head

This type of spray head sprays a fan shaped pattern of water. Interchangeable nozzles installed on the sprinkler, which determine the pattern (360°, 270°, 180° or 90°) and radius of throw. Some special types of nozzles are also available (Square, Centre strip, end strip, side strip etc.) for long narrow areas. The radius of throw and operating pressure of these

Table 1. The frictional losses in the lateral lines (Zone I)

Lateral nos.	Section	Flow rate cu.m/Hr.	Length (m)	Selected pipe dia (mm)	The frictional losses m/100 m	The actual losses (m)
l_1	Submain - S_1	1.04	0.5	25	10.0	0.05
	S_1 - S_2	0.86	4.0	25	6.0	0.24
	S_2 - S_3	0.52	4.0	20	8.5	0.34
	S_3 - S_4	0.34	4.0	20	4.0	0.16
					Total	0.79 < 1.4
l_2	Submain - S_1	0.88	0.5	25	8.0	0.04
	S_1 - S_2	0.70	4.0	25	3.0	0.12
	S_2 - S_3	0.36	4.0	20	4.0	0.16
	S_3 - S_4	0.18	4.0	20	1.0	0.04
					Total	0.36 < 1.4
l_3	Submain - S_1	0.52	0.5	0.20	8.5	0.04
	S_1 - S_2	0.34	4.0	20	4.0	0.16
					Total	0.20 < 1.4
l_4	Submain - S_1	0.34	0.5	20	4.0	0.16 < 1.4
l_5	Submain - S_1	0.52	0.5	20	8.5	0.04
	S_1 - S_2	0.34	4.0	20	4.0	0.16
					Total	0.36 < 1.4
l_6	Submain - S_1	0.88	0.5	25	8.0	0.04
	S_1 - S_2	0.70	4.0	25	3.0	0.12
	S_2 - S_3	0.36	4.0	20	4.0	0.16
	S_3 - S_4	0.18	4.0	20	1.0	0.04
					Total	0.36 < 1.4
l_7	Submain - S_1	1.04	0.5	25	10.0	0.05
	S_1 - S_2	0.86	4.0	25	6.0	0.24
	S_2 - S_3	0.52	4.0	20	8.5	0.34
	S_3 - S_4	0.34	4.0	20	4.0	0.16
					Total	0.79 < 1.4

Table 2. The frictional losses in sub-main line (Zone I)

Section	Flow rate cu.m/Hr.	Length (m)	Selected pipe dia (mm)	The frictional losses m/100 m	The actual losses (m)
l_1 - l_2	1.04	4.0	25	3.5	0.14
l_2 - l_3	1.92	4.0	40	1.5	0.06
l_3 - l_4	2.44	4.0	40	7.0	0.28
l_4 - Main line	2.78	2.0	40	17.5	0.35
Main line - l_5	2.44	2.0	40	7.0	0.14
l_5 - l_6	1.92	4.0	40	1.5	0.06
l_6 - l_7	1.04	4.0	25	3.5	0.14
				Total	1.27 < 1.4

sprinklers ranges between 2m-5m and 1.1 kg/cm² to 2.1 kg/cm² respectively.

Gear driven Sprinklers

In this type rotating stream / Jet of water is coming out from the nozzles while operating and this rotation is governed by the gear driven mechanism placed inside the sprinkler head. The radius of throw and operating pressur of this sprinkler heads ranges between 5-27r and 2.1 kg/cm² to 6.1 kg/cm² respectively. I general, spray head sprinklers may be use in the area heaving less than 6m width an gear driven sprinklers may be used for th area having more than 6m width.

Fig.1. Landscape irrigation layout

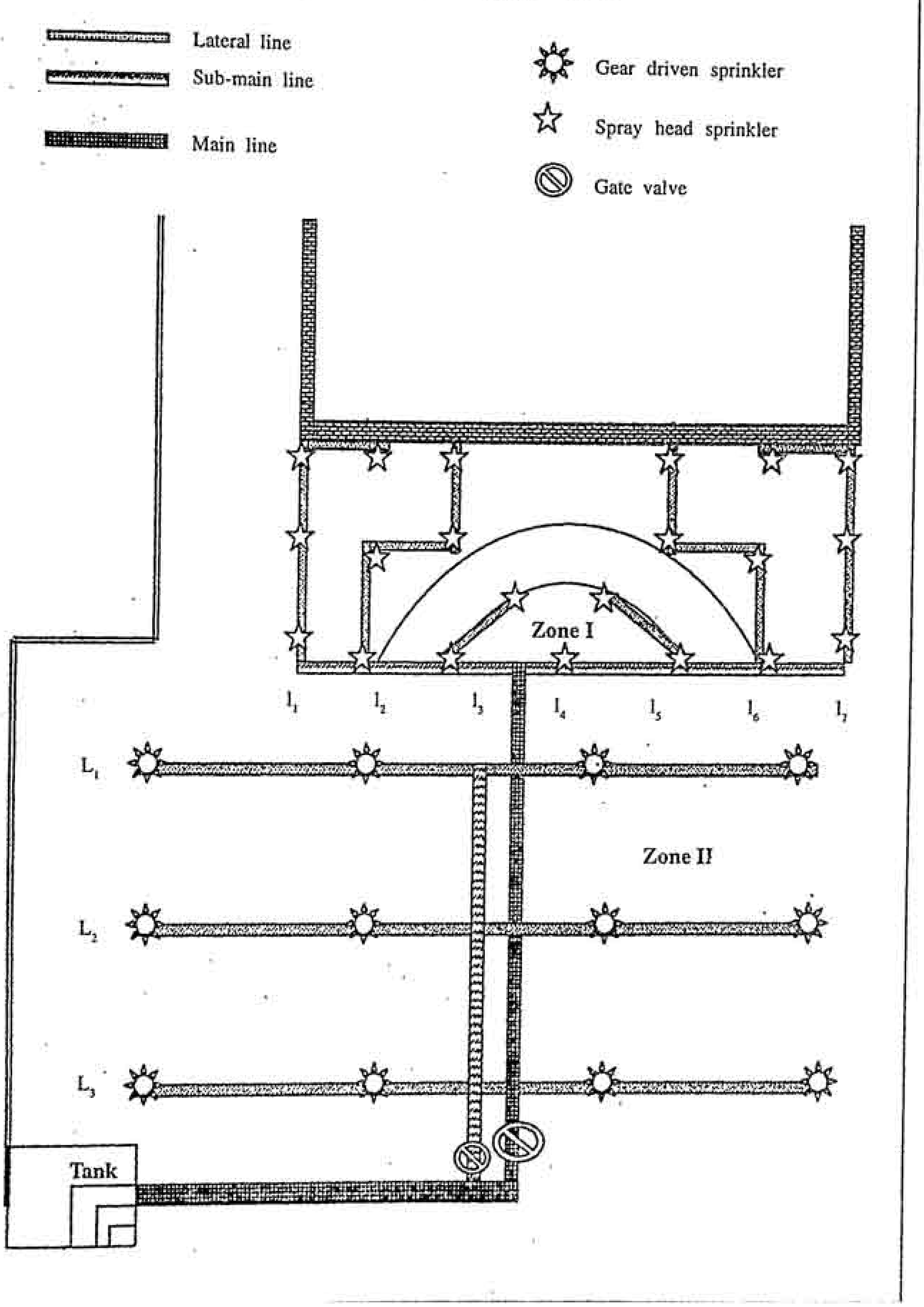

Table 3. The frictional losses in the lateral lines (Zone II)

Lateral nos.	Section	Flow rate cu.m/Hr.	Length (m)	Selected pipe dia (mm)	The frac-tional losses m/100 m	The actual losses (m)
l_1	S_1 - S_2	0.32	10.0	25	0.7	0.07
	S_2 - S_3	0.93	5.0	25	9.0	0.45
	Submain - S_3	0.93	5.0	25	9.0	0.45
	S3 - S4	0.32	10.0	25	0.7	0.07
					Total	1.04 < 2.5
l_2	S_1 - S_2	0.61	10.0	25	2.5	0.25
	S_2 - Sub main	1.83	5.0	40	2.5	0.125
	Sub main - S_3	1.83	5.0	40	2.5	0.125
	S_3 - S_4	0.32	10	25	2.5	0.25
					Total	0.75 < 2.5
l_3	S_1 - S_2	0.32	10.0	25	0.7	0.07
	S_2 - Sub main	0.93	5.0	25	9.0	0.45
	Sub main - S_3	0.93	5.0	25	9.0	0.45
	S_3 - S_4	0.32	10.0	25	0.7	0.07
					Total	1.04 < 2.5

Head Layout

Placing the sprinkler head over the landscape area in such a way that a uniform application of water is ensured is'called as head layout. There are two types of head layout, one is square pattern in which sprinklers heads are placed as square grid and next one is triangular pattern, where sprinkler heads are placed as equitriangular fashion. Advantage of the triangular pattern is high precipitation rate, results in less hours of operation and hence best suited for larger area. However triangular pattern may produce dry spots or uneven distribution in the corners. The distribution pattern of water from a sprinkler under favourable conditions of pressure and wind will be in such a way that the depth of application will be more near the sprinkler and it gradually' reduces towards the end point. To obtain high uniformity of water application, the wetted circle of adjacent sprinklers should overlap. Normally 100% overlapping is preferable i.e. the sprinklers should be placed apart with a distance which is equal of throw of the sprinkler. The industry standard for limiting the variation in performance between the sprinkler heads is as follows.

a. Lateral pressure loss may never be greater than 10% sprinkler operating pressure.

b. Pressure losses in sub-main lines should not be more than 10% of sprinkler operating pressure.

c. In main line the flow velocity should not exceed 1.5m/sec. The main line should run as efficiently as possible and also that should be the shortest possible route. Another important thump rule is that main line should be placed in such a way that part of the pipe (Lateral/Sub-main) should be on one side and the remaining on the order side. The reason is to balance the system there by reducing size of the pipes.

Materials and Methods

Study Area

The study was conducted in the landscaped area situated in front of the TNAU University Auditorium. The catch can readings were taken daily for one week during the first week of May 2001. The Fig. 1 shows all the parameters including water tank situated at one corner, road crossing, conduit pipe crossing etc. The area was divided into two zones 1 and Zone II for design purpose.

Zone 1

The width of the landscape area to be watered in Zone 1 is less than 6m, hence the spray head sprinklers (Nelson 6300 Series) were selected to cover this emitters width. The head layout for the Zone 1 is shown in Fig. 1.

The specification of spray head sprinklers for the area as follows:

Pop-up height : 4" from the ground level

Table 4. The frictional losses in sub-main line (Zone II)

Section	Flow rate cu.m/Hr.	Length (m)	Selected pipe dia (mm)	The fractional losses m/100 m	The actual losses (m)
Mainline - l_3	7.40	1.0	40	16.0	0.16
l_3 - l_2	5.54	10.0	40	8.0	0.8
l_2 - l_1	1.86	10.0	40	2.5	0.25
				Total	1.21 < 2.5

Table 5. The frictional losses in the main line

Section	Flow rate cu.m/Hr.	Length (m)	Selected pipe dia (mm)	The fractional losses m/100 m	The actual losses (m)
Tank - Zone II	7.40	20	63	3.2	0.64
Zone II - Zone I	5.22	30	40	6.8	2.04
				Total	2.68

Table 6. The coefficient of uniformity of landscape irrigation system

S.No.	Zone I		Zone II	
	Application rate (mm)	Numerical deviation	Application rate (mm)	Numerical deviation
1.	40.8	0.2	11.4	0.4
2.	42.4	1.4	12.2	0.4
3.	40.6	0.4	11.8	0.0
4.	43.2	2.2	10.8	1.0
5.	43.6	2.6	12.4	0.6
6.	39.7	1.3	11.8	0.0
7.	42.1	1.1	12.6	0.8
8.	41.4	0.4	12.3	0.5
9.	37.4	3.6	12.7	0.9
10.	43.6	2.6	11.9	0.1
11.	43.4	2.4	10.9	0.9
12.	42.8	1.8	10.3	1.5
13.	38.6	2.4	10.2	0.6
14.	41.8	0.8	11.1	0.7
15.	42.2	1.2	12.1	0.3
16.	42.1	1.1	12.6	0.8
17.	42.4	1.4	11.1	0.7
18	38.8	2.2	13.4	1.6
19	36.8	4.2	10.8	1.0
20	37.2	3.8	13.0	1.2
21.	41.0	0.0	11.8	0.0
b = 21	A = 41	$\Sigma x = 37.1$	a = 11.8	$\Sigma x = 13.4$

Zone I:
Cu = 110 x (1-Σx / ab)
= 100 x (1-37.1 / 21 x 41)
= 95%

Zone II:
Cu = 100 x (1-Σx/ab)
= 100 x (1-31.4 / 21 x 11.8)
= 94%

Spray trajectory : 30°
Radius of throw : 4m
Discharge : 0.68 cu.m./hr
Operating pressure : 1.4 kg/cm^2
Overlapping per cent : 100 percent

Zone II

Zone II has an rectangular shaped landscape area without any obstructions like road crossing, walkway etc. Also it has the area which has to be watered more than 6m. width. In such a condition, gear driven sprinklers (Nelson 6000 Series) which suits the situation was selected. The head layout for zone 11 is shown is Fig. 1. While designing with gear driven sprinklers, special attention should be taken while selecting the nozzles because if the same nozzle was used for all the full circle, half-circle and quarter-circle operation, the depth of application in half- circle area would be doubled and then in quarter cycle area would be quadrupled as chat of full circle. In order to obtain, uniform application over the entire area the nozzle should be selected such a way that the discharge capacity of nozzles of quarter, half and full-circle will be 1:2:4 ratio respectively.

Specifications for the sprinklers in zone II are as follows

Pop-up height	: 41' from the ground level
Spray trajectory	: 25°
Radius of throw	: 10 m
Operating pressure	: 2.5 kg/cm²
Overlapping percent	: 100 %
Nozzle discharge	: 0.32 cu.m/hr (Quarter-circle)
Nozzle discharge	: 0.61 cu.m/hr (Half-circle)
Nozzle discharge	: 1.23 cu.m/hr (Full-circle)

Pipe Sizing

As water moves through a pipe it loses pressure due to friction between the water and pipe inner surface, which is called frictional loss. The amount of frictional loss is determined by the type and material of pipes, the diameter of the pipe, discharge of water flowing through the pipe and the length of the pipe. These factors are then plugged into Hazen-William formula, which gives the frictional loss,

$$Hf = \frac{K.\ L.\ Q^m}{D^n} \times F \text{ where,}$$

K = $(3.59/C)^{1.852}$

Hf = Head loss due to friction, in

L = Length of the pipe, M

Q = Discharge through the pipe at the inlet, m^3/sec

D = Diameter of the pipe, m ,

C = Hazen-William's friction coefficient = 150 for plastic pipe

m = 1.852

n = 4.871 in Hazen- William's formula

F = Multi-outlet pipe pressure reduction factor (Scaloppi, 1998).

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

(Christiansen's Formula).

N = No. of outlets

The simplest and quickest method of finding the sizes of the pipes are by determining the maximum allowable pressure losses in each pipe. Keeping this value as a maximum limit the smallest possible pipe sizes can be obtained.

Performance Evaluation

The main objective of the landscap irrigation system is to apply calculated dept of water uniformly at a predetermined applicatic rate. The irrigation efficiency of sprinklers depenc upon the degree of uniformity of water application water spray distribution characteristics of sprinklers operating pressure, their spacing and wind velocity The uniformity coefficient was computed fron field observations of the depth of water collectec in catch cans placed at regular intervals withir the sprinkling area. It is expressed by the equatio developed.

Cu - 100 [1.0 - (Ex/ab)] Where

Cu - Uniformity coefficient (in per cent)

a - Average application rate (mm)

b - Number of observation points

Ex - The sum of numerical deviation of individua observation from the average applicatio rate

The field tests were conducted in zon I and it between four sprinklers for one hou and catch cans were placed one meter apar in zone I and 2.5 meter apart in zone

Results and Discussion

Hydraulic Design

In zone 1 there are seven lateral line (1_1, 1_2.............1_7) and in each lateral line th pressure drop should not exceed 1.4 m whic is 10% of sprinkler operating pressure. Wit this maximum limit and by determining th flow between each sprinkler, the smallest possibl size of the laterals can be found. In 1_1, fror sub-main to first sprinkler point, the flow was 1.04cu.m/hr and the length of the pipe was 0.5 m then the frictional losses for the above said discharge in 25mm pipe will be 10 m per 100 m length (From Hazen - William's Frictional Loss chart). Therefore, for 0.5m length, the losses will be 0.05 m. Then the flow between first sprinkler to second sprinkler was 0.86 cu.m/hr and the distance was 4m. The frictional losses for this discharge in 25 mm pipes will be 6m/100m length. Therefore for 4m length, frictional losses will be 0.24 m. In the same way, the frictional losses are calculated for all the laterals (Scaloppi, 1993) and the same was illustrated in the Table 1.

In designing the sub-main line, the maximum allowable losses will be 10% of the sprinkler operating pressure (1.4m), which was taken as a maximum limit with the carrying of each lateral, the pipe sizes were selected in such a way that losses should not exceed 1.4m and same is illustrated in the Table 2.

The total losses in the sub-main line was 1.27m which was less than 1.4m. Suppose, a 25mm diameter pipe was used in between 12 and 13, 15 and 16, the total losses would be 1.85m which is greater than 1.4m. So the pipe size was increased from 25 mm to 40mm diameter. In zone II the maximum allowable losses in laterals should be 10% of sprinkler operating pressure and hence the maximum limit for frictional losses in laterals as well as sub-main line can be 2.5m. By keeping this as a maximum limit, the smallest possible sizes were designed and illustrated in the Table 3 and Table 4 with their frictional losses.

Main-line sizing

The sizes of the main line can be selected by determining the flow rate in the pipe. The total discharge capacity of all the sprinklers in each zone will give total capacity of each zone I and gear driven sprinklers were used at zone II. At any case, the gear driven sprinklers and pop-up spray head sprinklers should not be operated simultaneously due to its difference in operating pressure. The zone having highest flow rate was taken to find out the sizes of the main line. The velocity of water flow in pipes should not exceed 1.5m/sec. By keeping this as a design criteria, the size of the main line was calculated with their losses and illustrated in the Table 5.

Christiansen's uniformity coefficient (CUC)

To calculate the Christiansen's Uniformity Coefficient (CUC) field test was carried out by using the catch can test which are explained in the following figure in which S represents the sprinklers.

		Zone I		
S	40.8	42.4	40.6	S
43.2	43.6	39.7	40.8	41.4
37.4	41.6	43.4	42.8	38.6
40.8	42.2	42.1	42.4	38.6
S	36.8	37.2	39.0	S
		Zone II		
S	11.4	12.2	11.8	S
10.8	12.4	11.8	12.6	12.3
12.7	11.9	10.6	10.3	10.2
11.1	12.1	12.6	11.1	13.4
S	10.8	13.0	11.8	S

The coefficient of uniformity was calculated for zone I and II and same is illustrated in Table 6. The readings shows that both pop-up spray head and pop-up gear driven sprinklers are yielding high distribution uniformity.

Conclusions

The landscape irrigation and water conservation are two inseparable rails on which the vehicle of urban beautification needs to be launched. The satisfactory performance of this system rests primarily on a correct set of operation pressure head of the sprinklers and uniformity of water distribution. The landscape irrigation system tried in Tamil Nadu Agricultural University campus serves an illustrious monument and a role model in the arena of landscape development.

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