Optimization of Irrigation Design Technique for Pumping Units through Software Simulation Analysis for Varied Landscapes

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Abstract. This investigation will contribute in the evaluation of pump duty parameters required to design a system comprising of underground pop-up type sprinklers for irrigating turf grass lawn for a proposed site. The study specifically describes the design techniques of irrigation pipeline network of varied zones of landscape areas distant apart operating with minimum pumping units. The entire landscape area is designed with underground pop-up type sprinklers with proper selection spacing over the lawn. A method is proposed comprising of sprinklers, pipes diameters using pipe network simulating software where energy cost can be reduced. The study shows techniques on proper pump selection for landscaping. The labor cost, energy usage and water wastage has been tremendously reduced and optimized. Observations reveal varied pump parameters in that system for varied zones. This method reduces the various pumping units sectioning zones which can satisfy the maximum duty parameters of a single centrifugal pump of the landscape. This manuscript further elaborates on the practical aspects for the design of an efficient system.

1. Introduction
Architectural Landscaping should be perceived as an efficient irrigation system because water is supplied to a targeted area whilst reducing the evaporation and transpiration losses. The process of flooding or surface drain irrigation technique wakes way for considerable loss in irrigation water due to evaporation, whilst further affecting the aesthetics of a landscape. Controlled irrigation systems apply optimum water quantity directly to plants for maintaining favourable soil moisture conditions. Nowadays, various micro-irrigation technologies are available even in kit for reducing water use for residential homeowners [1-2].

The lawn course area looks more aesthetically pleasing if incorporated with sub-surface irrigation. The system bears a close resemblance to sprinkler irrigation as the water is distributed by the usage of pipes and sprinklers. The pipeline, unlike sprinkler irrigation, is concealed below the surface. Subsurface irrigation effectively works in windy, warm and dry regions. It conserves water by minimizing the evaporation loss and also aids in reducing weed growth. The pipelines are also sheltered from apparent damage which might be caused from surface exposure. Such system not only reduces intensive labour participation from doing monotonous work of watering the lawn but also saves time with greater efficiency. Research had been done for optimization technique by estimating the optimum looped water supply pipeline design in agricultural irrigation [3].

Irrigation scheduling of landscape is a vital factor which could be incorporated in various controlling technologies properly [4]. Overhead, broadcasting irrigation methods may be ideal for turf grass, but the precipitating rate of sprinkler must be uniform over the planting area. The overhead sprinkling
irrigation causes wastage of water over non-grass areas and promotes weed growth as their discharge are high and sometimes deliver more water than the actual requirement of plants. Hence overhead irrigation system although conventionally used, is not regarded as the best approach. Such system is unable to deliver water precisely in optimum quantity to different varieties of plants in the ground area where as drip system has that flexibility to some extent. Design approach towards the optimization of water application fails to offer the high efficiency where there is high variation water demand of plants. The design approach depends not only on planted area, but also on the water demand, soil structure and root zone of the plants. Such design leads to high efficiency of the system [5]. It has been revealed that more than 60% of losses occur in the pipeline network and valves. So understanding of the basics of hydraulics is an important factor [6-7]. The overall frictional losses that can cause pressure transiency and create stress on the pipeline system are all judged using various pipe network hydraulic simulating software like EPANET and HAMMER [8-10] etc. Hydraulic simulation software like WaterGEMS could be used as a tool in research for irrigation pipeline distribution.

2. Materials and methods
The study focuses on the pipeline networking analysis at the proposed site of Calcutta Riverside, South-24 Parganas, India. The architectural drawing indicating the irrigation areas like lawn and other plantation zones have been considered for the study. The co-ordinates are 22°30′2.2″ N & 88°13′49.4″ E as viewed in figure 1.

The study helps to design and evaluate the flexibility of the irrigation system through proper pump selection. Specific objectives are established as follows. The layout map for the whole proposed site was studied. Study area focused on design techniques on selecting the pump and software simulations for piping systems. The site map was collected and the landscape area was delineated where there is lawn, turf, shrubs, trees, etc. A comprehensive field survey was done to locate the water sources and to check if any deviations occurred with the original design layout. The total survey was done with GPS receiver to get exact measurement of elevation, latitude, longitude, length or any other required data. In-house work started with the sprinkler selection as per the site. Sprinkler to sprinkler spacing is well maintained to reduce the head to head overlapping space. No lawn area had been left vacant or with weak overlapping. As per suitable operational purposes the whole landscape area has been divided into four numbers of phases viz. Phase -I, Phase -II, Phase -III and Phase -IV, highlighted in Figure 2.

![Figure 1. Study location](image-url)
This has been deliberately done to divide the command area with four different water sources to minimize water stress at any single point whilst also maintaining the techno-economic viability of the system. The water sources have been selected according to accessibility such as borewell, pond and water from sewage treatment plant. For the design purposes, phases have been divided such that the water sources remain located mostly in the center of each phase, allowing uniform pipe network distribution. The required quantity of pipes and sprinklers in all the four phases are high so we focus on single phase that is Phase - I as given Figure 3.

**Figure 2.** Phase wise division of proposed site

**Figure 3.** Landscape area of Phase - 1
Figure 4. Pipe network system of Phase- I in software

The network simulation and analysis was performed in WaterGEMS software and by dividing the varied landscape area in accordance to the required number of sprinklers into different cases (figure 4), where each case would be operated singly through individual Flow Controlling Valve (FCV). The identification and selection of appropriate sprinkler is the foremost job in the design of an irrigation system for landscape areas. Pop-up type sprinklers were selected for the lawn areas whilst for shrubs standing sprinklers are selected as per the width. The sprinklers were placed in a way such that no water would splash into undesirable regions viz. in roads or other service areas. The sprinklers which were selected had the capacity of regulating the flow at any direction for covering the areas. Some areas the lawn is restricted for part-circle (PC) movement of sprinklers. After selection and placement of all sprinklers, total discharge in each zone was calculated. Two type sprinklers of Rain Bird Corporation, Azusa, California was selected. One is a rotor type sprinkler model name Maxi-Paw (SAM) 2045A and other is a sprayer type termed as UNI-Spray Series model 12 Series Variable type Arc Nozzle (VAN). These pop-up sprinklers are adjustable at all arcs. The spacing of nozzles at proper position eliminates dry patches over lawn which facilitates uniform growth. Sprinklers are generally suggested to place in head-head spacing for 100% overlapping. The uniformity distribution of water droplets coming out of the orifice of sprinkler are not even at all position, the nearby range has lesser water uniformity than the outer periphery. Thus sprinkler to sprinkler spacing supplements the coverage. The sprinklers were set in triangular spacing in a zigzag position. The discharge estimation from the sprinkler nozzle was calculated by the following equation:

\[ q = kp^{0.5} \]

where; \( q = \) flow (lpm); \( k = \) nozzle discharge co-efficient (lpm/bar); \( p = \) pressure (bar).

The pipeline was drafted in AutoCAD avoiding road crossing as much possible and maximizing the number of mainlines from a single pumping point. The total discharge has been divided further for pumping unit selection whilst maintaining similar discharge at each zone of operation. The available layout map along with sprinkler and pipe distribution network was drafted in AutoCAD which had been then modelled into software. Accordingly the whole pipe network was drawn which include the
whole served area for landscapes. The network was simulated and analyzed. A technique was used with sprinklers such that the minimum requirement of pump set would feed water for maximum sections, provided that all sections do not work together. Figures 5-6 show several FCVs and Discharging to Atmosphere (D2A) pop-up type sprinkler connecting from nodes. For any instance while computing the FCV-2 is active or open then other FCVs such as FCV-3, FCV-4, FCV-5, FCV-6, FCV-7, FCV-8, FCV-9, FCV-10 will be closed or inactive. Here the symbols P-, J-indicate pipe, junction associated with their individual numbers.

**Figure 5.** FCVs for various sections in an irrigation network system of Phase - I in software

**Figure 6.** Piping layout and sprinkler position in software

In the layout the hydraulic modeling has been worked out in following process for pipeline network: The reservoir was drawn first then associated pump was drawn, the connecting links as pipes, valves, sprinklers and junctions were later joined to the water sources. Initially a pump was chosen whose flow rate, corresponding head, pump-duty parameters were entered. Selections of pipes and length (as per drawing), diameter, roughness coefficients were also entered. Once the network in software was
completed then pipe diameter simulation was performed. The results such as pressure, frictional head loss, velocity, and flow from all pipes were saved. The fluid was considered to be apparently clean water and homogeneous in nature. Elasticity of the fluid and pipeline material follows linear pattern. The flow is one dimensional and incompressible. The software uses average velocity. All new pipes were considered of Polyvinyl chloride (PVC) material and having the same roughness co-efficient as 150. The average temperature was assumed at 20° C for software simulation. Pipes were linked to feed water in the network from one-point to another. Software assumes that pipes flow at full-flow conditions at all times. Flow directions shown after running the system are actually the flow from end at higher potential of pump to lower potential. The frictional head loss due to the inner side-walls of the pipe was calculated using Hazen-Williams equation:

\[ H_f = A q^B \]  \hspace{2cm} (2)

where; \( H_f \) = head loss; \( A \) = resistance co-efficient; \( q \) = flow rate; \( B \) = flow exponent.

Minor losses occur due to water turbulence caused in all pipe fittings like bends, tees, etc. Minor losses were calculated using the equation:

\[ H_f = K v^2 / g \]  \hspace{2cm} (3)

where; \( H_f \) = minor head loss; \( K \) = minor loss co-efficient; \( v \) = flow velocity (m/s) ; \( g \) = acceleration due to gravity (m/s\(^2\)). In Phase- I there are nine cases that been studied. The pop-up type sprinkler system of Case-1 irrigating the field (0.031 ha) has been drawn. As per suitable spaced area for Case-1 UNI-Spray 12 VAN Nozzle sprinklers are placed and all the technical required data like elevation, discharge element type, typical flow, and typical pressure drop was fed in software flex table of D2A.

**Table 1.** Flex sheet showing FCV-2 is active and others are closed in software.

| Label | Length (m) | Start Node | Stop Node | Pipe Dia. (mm) | Headloss (m) |
|-------|------------|------------|-----------|----------------|--------------|
| P-1   | 19.2       | R-1        | S-1       | 90             | 0.046        |
| P-2   | 14.4       | S-1        | PMP-1     | 90             | 0.033        |
| P-3   | 9.6        | PMP-1      | TCV-1     | 90             | 0.020        |
| P-4   | 8.4        | TCV-1      | J-1       | 90             | 0.020        |
| P-5   | 13.2       | J-1        | FCV-1     | 90             | 0.033        |
| P-6   | 384        | FCV-1      | J-2       | 90             | 0.876        |
| P-7   | 7.2        | J-2        | FCV-2     | 75             | 0.039        |
| P-8   | 54         | FCV-2      | D2A-1     | 75             | 0.301        |
| P-9   | 48         | D2A-1      | D2A-2     | 63             | 0.059        |
| P-10  | 36         | D2A-2      | D2A-3     | 63             | 0.039        |
| P-11  | 36         | D2A-3      | D2A-4     | 63             | 0.033        |
| P-12  | 36         | D2A-4      | D2A-5     | 63             | 0.033        |
| P-13  | 36         | D2A-5      | D2A-6     | 63             | 0.026        |
| P-14  | 36         | D2A-6      | D2A-7     | 63             | 0.026        |
| P-15  | 36         | D2A-7      | D2A-8     | 63             | 0.020        |
| P-16  | 48         | D2A-8      | D2A-9     | 63             | 0.026        |
| P-17  | 36         | D2A-9      | D2A-10    | 63             | 0.020        |
| P-18  | 36         | D2A-10     | D2A-11    | 63             | 0.013        |
| P-19  | 36         | D2A-11     | D2A-12    | 63             | 0.013        |
| P-20  | 36         | D2A-12     | D2A-13    | 63             | 0.007        |
| P-21  | 36         | D2A-13     | D2A-14    | 63             | 0.007        |
| P-22  | 36         | D2A-14     | D2A-15    | 63             | 0.007        |
| P-23  | 36         | D2A-15     | D2A-16    | 63             | 0.007        |
| P-24  | 36         | D2A-16     | D2A-17    | 63             | 0.003        |
| P-25  | 36         | D2A-17     | D2A-18    | 63             | 0.003        |
| P-26  | 36         | D2A-18     | D2A-19    | 63             | 0.003        |
| P-27  | 36         | D2A-19     | D2A-20    | 63             | 0.003        |
| P-28  | 36         | D2A-20     | D2A-21    | 63             | 0.003        |
The vertical height difference from the pumping source to the highest elevation at which the sprinkler situated is at 2.0 m in that area. As all the 21 sprinklers used are of the same type so the specifications were unchanged. The discharge of each sprinkler is 0.1220 (L/s), which sprinkles upto a range 3.2 m and operates at 150.0 (kPa) or 1.5 (kg/cm²). The value of initial status was open, which means all sprinklers are operating at same time when FCV-2 is active. The irrigating system comprising of a pumping unit, mainline, the sprinkler line, the sub mains and FCVs; the same pump is run for all other cases. FCV-2 is responsible for operating all the sprinklers of Case-1 section for this green zone. If the FCV-2 is open or active and remaining FCV-3 to FCV-10 are closed or inactive. Hydraulic headlosses are associated in all pipes for Case-1 when FCV-2 is active. In similar fashion all cases were studied. All the technical required data was fed in all the flex sheets of software for the Case-1 and the for PVC pipe diameter of 90 mm, 75 mm and 63 mm with pressure of Class III to maintain the required flow. The table 1 shows the generated data after the program is RUN fixing Case-1 (FCV-2) as active and remaining eight FCVs as closed. The dynamic head losses are calculated in the software itself to produce its system pump curves obtained using software. The system pump head as generated includes operating pressure; it is the pressure head at which sprinklers get pop-up and showers. Similarly all nine cases are studied, in similar fashion flex tables and individual system pump curves are obtained. Initially comparison of all the system pump curves of all cases with the selected pump was performed. The duty parameters of our chosen horizontal centrifugal pump of capacity 7.5 Horsepower (HP) of Kirloskar make (Model – KDS 864+) is fed in the program to verify whether our selected pump is suited and thus claim the justification of this design. In our Phase-I, there are nine cases that been studied say for an instance Case-1 as sited in figure 7 the green bounded landscape area in AutoCAD drawing. The computed flex table of Case-1, generated from software is shown in Table 2, where the column OD of PVC pipe is analyzed and simulated to achieve desired velocities. From the reservoir indicated by R-1, S-1 we have selected 90 mm OD (Outer Diameter) PVC as the delivery pipe from PMP-1 (pump for Case-1). For Case-1 the flow is 2.56 L/s where it can be chosen smaller diameter since other eight cases having higher flows flowing from the same pump and same mainline so 90 mm pipe size as the mainline was chosen for Case-1.

![Figure 7](Figure-7.png)

**Figure 7.** Landscape showing labelled green area (0.031 ha) of Case-1 under consideration

| ID | Label | Elevation (m) | Status (Initial) | Flow (Typical) (L/s) | Pump Head (m) |
|----|-------|---------------|------------------|---------------------|---------------|
| 31 | PMP-1 | 1.0000        | On               | 2.56                | 18.71         |

**Table 2.** Flex sheet of pump in software.
3. Results and discussion
The study of landscape irrigation system, where pumping units required for the distribution network of site was analyzed herein. Detailed analysis of the suitability of the selected pump was performed and the requirement of any alternative pump for all the nine cases was analyzed (figures 8-9).

It is seen that only one pump coincides its operating conditions with our selected pump and rest are not satisfying the conditions. Figure 8 clearly shows duty parameters of individual conditions and clearly indicates for Case-3, Case-4 and Case-6 that only one pump is suitable. Others have different characteristics which need more manipulations and break into more sections. The graphs show that the initially selected pump do not satisfy for all nine cases as there are operating pressure differences of different sprinklers. So, to optimize the design two more pumps need to be added to complete the Phase- I operation. In the distribution graph points of figure 9, the combined discharges of Case – 1 and Case – 2 can be labeled as case 1 & 2 and put in a combined graph then a pump of P3 can satisfy four cases viz. Case 1 and Case 2, Case – 5, Case – 9, while pump P2 can satisfy Case–3, Case–4, Case–6. The initially selected pump P1 can satisfy Case- 7, Case -8. A variation of 10% headloss and discharge can be managed by assembly valves and FCVs for the three pumps.
4. Conclusions

The riddles of successful a design depends on the identification, selection, and suitable placement of pop-up sprinklers eventually keeping the knowledge of all its technical specifications, its efficiency and finally the economic viability at the beginning of the designing process. The design is done successfully considering conditions of the site as per drawing. Since the study was designed and the simulations were performed with the aid of WaterGEMS software, the probability of error is immensely reduced. From the analysis, it has been seen that the single pump that was selected for operating nine sections individually would sometimes give very high head with corresponding low discharge for some sections. To some extent pipes can withstand pressure but if there is sudden high rise in pressure it may collapse the whole system. So an automatic PRV and by-pass assembly would be highly necessary to release the excess pressure. This would increase the automation cost and energy consumption but would greatly reduce the risk of system failure later in the system. The design justifies the optimization of landscape irrigation through software simulation and minimum numbers of pump to operate all large and small areas of landscape zones.

In any micro-irrigation system software application plays a big role in the designing accuracy. The complications or hurdles in the design of such a system without the use of computer simulations lie in calculations and simulations for systems with numerous sections; detailed pipes network, valves, and sprinklers of different types can create chances of error on human calculation. The use of software simulation for the design of such systems also reduces the time required whilst increasing the accuracy and precision of the design.

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