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Designing an efficient and stable household Irrigation system

PB Sob

Department of Mechanical Engineering, Faculty of Engineering and Technology, Vaal University of Technology, Vanderbijlpark 1900, Private Bag X021, South Africa.

Abstract

The continuous growth of population is impacting domestic water supply mostly in Southern Africa. The recent drought due to climate change is marking a bad situation worst. Low pressure is commonly observed in most household in South Africa due to low water storage in most dams. This is due to high demands of water needed by the growing population. To fulfil the supply of water demand of the continuously growing population, it is vital to provide sufficient and uniform quantity of water through a designed network of pipes. For this purpose, it is vital to look at the design of household irrigation system.

The main aim of the current study is to design an irrigation pipeline system that will deliver the right pressure and flow rate required during. To achieve this different designed study of irrigation system was theoretically modelled and their pressure and flow rate investigated. Different irrigation performance were revealed. The system with the best pipeline network for the irrigation system was revealed in the current study. The system gave the best possible irrigation during operation. The required pressures and the volume of flow rate during operation were acceptable.

Keywords: Design, Efficient, Irrigation and household.

INTRODUCTION

To provide water demanded to the continuously growing population, it important to provide sufficient and uniform quantity of water through the water supplied designed pipe network. In recent years, the infrastructure for collection, transmission, treatment, storage, distribution of water for domestic, industrial, commercial, and irrigation, as well as for such public needs' better street flushing system. A design water supply system that is more efficient and stable should meet requirements for public, industrial, and commercial industrial. Most domestic irrigation system are inefficient during operation with several blockages being reported during winter in South Africa. The problem is more severe in most public health department in South Africa. Most developed counties are using EPANET software to monitor this problem. Water is vital need as we need water to grow food, power generation and water is needed to run our industries. We also need water in our daily lives as our bodies needs water daily for smooth functioning. Normally we need an average of about 70litres per person per day and therefore the draining system needs to flush out that same quantity of water daily. The main effects of inadequate water supply of water may cause several diseases. It also has an economic impact as time and energy expended in daily collection and high unit costs being reported daily. The provision of basic daily water supply is yet to be regarded by most developing countries in Africa. The department of water and sanitation is still given low resources making the problem more complex to manage. Climate change will impact the department of water and sanitation in South Africa. Companies are growing, population are growing and if the problem of water is not well address the crisis will lead to a national disaster by 2030. Most developed counties use EPANET is a computer program tool and performs extended period of hydraulic simulation of water quality behavior within pressurized pipe networks during operation. A pipe system network consists mainly of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs and this contributes to major and minor losses in the system. EPANET system also tracks the varying flow of water in each pipe, the actual pressure at each node, the height of water in each tank, and the concentration of a chemical in the system and pipes network during operation. The irrigation system is also impacted by chemical toxics and impurities which makes the problem more complex. In most developed counties several stages are already in place to monitor a water supply system as an EPANET is used as a research tool for improving the understanding the flow of drinking water constituents in a water distribution system. Therefore, the EPANET is a vital tool being used in water management strategies. Most irrigation system cannot be control or properly manage by the EPANET system. It is therefore important to study and design an efficient irrigation system. Therefore, the aim of the current study is to design an irrigation pipeline system that will deliver the right pressure and flow rate required during operation. It will also be vital if the irrigation system can be automated as proposed in this study. This will save energy and cost during operation.

METHODOLOGY

The tree or branched pipe system design will solve the current problem of lack of sprinklers coverage irrigating the whole surface area of the household garden. The tree system allows the garden to be divided into zones and this makes it possible

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for the irrigation system to be operated with a smaller booster pump since the garden can be irrigated in sections. The system offers the following advantages and advantages such as, an overall design calculation are easy and simple, land can be divided into zones and can be watered independently, it uses very few cut off valves and has a very low operation and maintenance cost, the design pipe system is simple. The system is not good at maintaining satisfactory pressures to areas located further away for the main line, only one main line supplies the water and head losses are very high therefore large pipe diameters are and large pumping units are required.

Figure1. New Pipeline system design

Forces Inside a Pipe System during operation

There are three different terms used to express the quantity of a fluid flowing at a section in a system per unit time, these are volume flow rate, mass flow rate and weight flow rate (Robert L Mott, Joseph A, 2014).

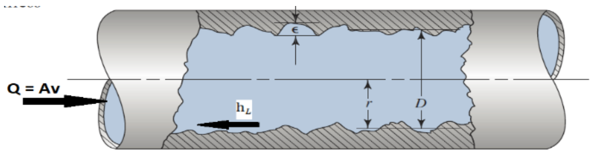

Figure 2. Volume flow rate inside a pipe

Volume flow rate (Q), Q = Av (m3/s), v-max = 1.5m/s to avoid water hummer

A – Area(m2), v – velocity (m/s), shear stress (τ) given as $\tau = \eta \frac{\Delta v}{\Delta y}$ and η – Dynamic viscosity $\frac{\Delta v}{\Delta y}$ – velocity gradient. Branching and parallel pipeline system provide more than one fluid flow path from the source to the destination point. P – Pressure inside a pipe, this force pushes against the pipe walls and tends to cause the pipe to burst if it exceeds the pipe's operating pressure limit.

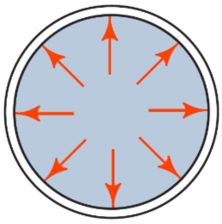

Figure 3. Pressure inside a pipe

v – Is the rate at which a fluid moves inside a pipe. The higher the velocity the greater the friction losses inside the pipe. According to (Rain Bird) it was discovered that a maximum velocity flow rate of 1.5m/s is acceptable. Velocities that are less than 1.5m/s result in less pipe damage from pressure surges. Losses in pressure due to friction increase rapidly for velocities greater than 1.5m/s. z – Elevation of the pipe from a common ground reference point, hA – energy added to the fluid by for example a pump, hL – energy losses due to minor losses (fittings and valves) or friction in pipes. This depend on the pipe material and other factors during temperature.

Pipe Material

The pipe material that is going to be used in the irrigation system is PVC. The pipe sizes are going to be determined according to the design pressures and flow rates of the water inside the pipe for each network branches, so that the right sizes are used for the system to function efficiently. PVC characteristics and its benefits were discussed in detail in 2.2.6, rigid PVC has 34 – 62MPa tensile strength. PVC has a melting point of 100 – 260°C. PVC falls under plastics pipe therefore its pipe wall relative roughness (ε) is 3.0x10-7m.

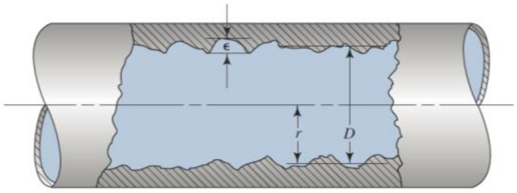

Figure 4. Frictional losses inside a pipe due to pipe wall roughness.

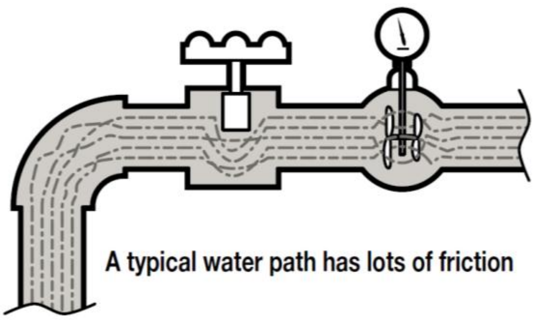

Figure 5. Water flow path with frictional losses due to pipes and fittings

Reynolds number NR, $N_R = \frac{\upsilon D \rho}{\eta}$, If NR < 2000, the flow is laminar, If NR > 4000, the flow is turbulent, $f = \frac{64}{N_R}$ Friction factor for laminar flow, $f = \frac{0.25}{\log\left[\frac{\varepsilon}{3.70}+\frac{5.74}{N_R}\right]^2}$ Friction factor for turbulent flow, $h_L = K\,\frac{v^2}{2g}$ (fittings and valves), $h_L = f\,\frac{L}{D}\,\frac{v^2}{2g}$ (Frictional losses), where;

f – Friction factor, L – Length of pipe, D – Diameter of the pipe, v – Average velocity, hR – energy removed from fluid e.g. a mechanical motor. The general energy equation of the system is given as

$$\frac{P_1}{\gamma} + \frac{v_1{}^2}{2g} + z_1 + h_A + h_L + h_R = \frac{P_2}{\gamma} + \frac{v_2{}^2}{2g} + z_2 \qquad [1]$$

Dynamic viscosity (η) which is the measure of a fluid internal resistance to flow. The dynamic viscosity of water at 25°C is 8.90 × 10−4 Pa·s and the Branched pipe layout patterns is given below

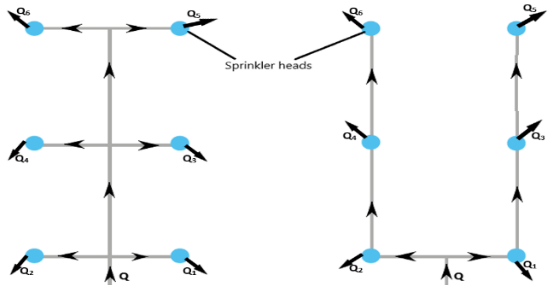

Figure 6. Branched pipeline system

System Assumptions are that the amount of fluid supplying sprinkler heads is equal to the sum of all the water discharged by each sprinkler head. Sprinklers used in each zone will discharge the same amount of fluid. Continuity Equation for a branched system is given as

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 \qquad [2]$$

According to tests conducted by the Center for Irrigation Technology (CIT) to test the most efficient combination of sprinkler nozzles to apply water. It was found that the area under 60% of the sprinkler's distribution radius is the area that received sufficient water for plant growth without the need for sprinkler overlapping. Beyond this 60% line the volumes of water diminish as you move further away from it and becomes less effective to support plants.

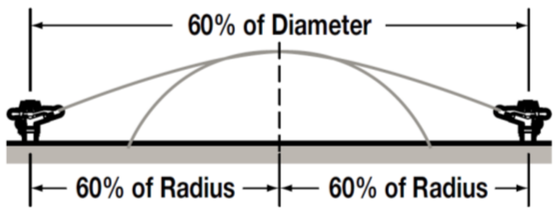

Figure 7. 60% diameter sprinkler spacing

To determine the number of sprinklers required by the residential area, measure and draw the property or obtain a google maps image of the property and then use any CAD software to draw the property to scale. All the property details such as walls, walkways, fences and driveways need to be indicated on the drawing. From the drawing the property will need to be divided up into zones such as back yard, front yard, side yard, lawns, flowers, etc. Sprinklers are selected according to their applications and also using the same type of sprinklers for each zone. Figure 8 below shows how sprinklers should represented on the property drawing.

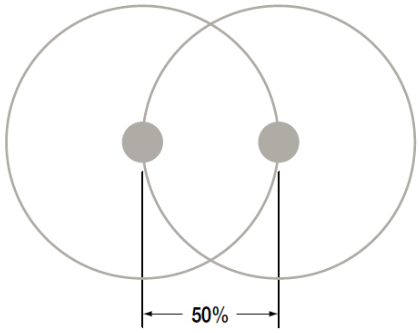

Figure 8. Sprinkler spray representation on property drawing

Pipeline sizing

Pipe sizing in sprinkler systems is done in reverse. The first pipe to be sized will be the one that supplies a sprinkler furthest from the valve. After this pipe size is established, the next pipe that supplies the last two sprinklers should be sized. This process is followed moving backwards from the last sprinkler and towards the valve and it is also impacted by the pipeline design parameters.

Pipeline Design Calculations for Sprinkler selection

To determine the number of sprinklers required the property needs to be drawn to scale and arcs are drawn on the drawing according to the size of the water distributing sizes of the sprinklers. The sprinklers are spaced at 50% of their distribution radius.

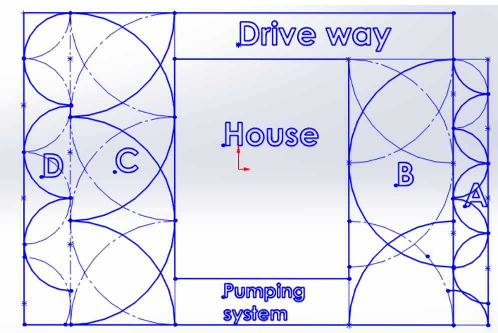

Figure 9. Sprinkler layout and spacing

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The residential garden has divided into zone: A – Outside front yard garden, with 12H Series MPR spray nozzles, radius 3.7m, quantity 8. B – Front yard with 3504 Series nozzle rotors, radius 9.1m, and quantity 6. C – Backyard with 3504 Series nozzle rotors, radius 9.1m, and quantity 8. D – Backyard flower bed with 12H series MPR spray nozzles, radius 3.7m, and quantity 7. The series and nozzle performance are shown below during operation.

3504 Series Nozzle Performance METRIC

Pressure bar	Nozzle	Radius m	Flow m^3/h	Flow l/m	■ Precip mm/h	▲ Precip mm/h
1.7	0.75	4.6	0.12	2.04	12	14
	1.0	6.1	0.17	2.91	9	11
	1.5	7.0	0.24	4.01	10	11
	2.0	8.2	0.32	5.30	9	11
	3.0	8.8	0.49	8.21	13	15
	4.0	9.4	0.67	11.24	15	17
2.0	0.75	4.8	0.13	2.24	12	13
	1.0	6.2	0.19	3.14	10	11
	1.5	7.0	0.26	4.35	11	12
	2.0	8.2	0.34	5.74	10	12
	3.0	9.1	0.53	8.87	13	15
	4.0	9.7	0.73	12.17	16	18

Figure 10. The rotor sprinkler

12 Series MPR METRIC

30° Trajectory

Nozzle	Pressure bar	Radius m	Flow m^3/h	Flow l/m	■ Precip mm/h	▲ Precip mm/h
12F	1.0	2.7	0.40	6.8	55	63
	1.5	3.2	0.48	8.3	47	54
	2.0	3.6	0.59	9.7	46	53
	2.1	3.7	0.60	9.8	44	51
12H	1.0	2.7	0.20	3.4	55	63
	1.5	3.2	0.24	4.2	47	54
	2.0	3.6	0.30	4.9	46	53
	2.1	3.7	0.30	4.9	44	51
12Q	1.0	2.7	0.10	1.7	55	63
	1.5	3.2	0.12	2.1	47	54
	2.0	3.6	0.15	2.4	46	53
	2.1	3.7	0.15	2.5	44	51

Figure 11. Spray nozzles

Zone water requirements: Zone = (Flow capacity) x (number of emitters)

A = 0.30x8 = 2.4m3/hr, B = 0.53x6 = 3.18 m3/hr, C = 0.53x8 = 4.24 m3/hr, D = 0.30x7 = 2.1 m3/hr. preliminary layout were being done and test in the current study. Preliminary Ideas for Pipe layout. *Preliminary Idea 1*

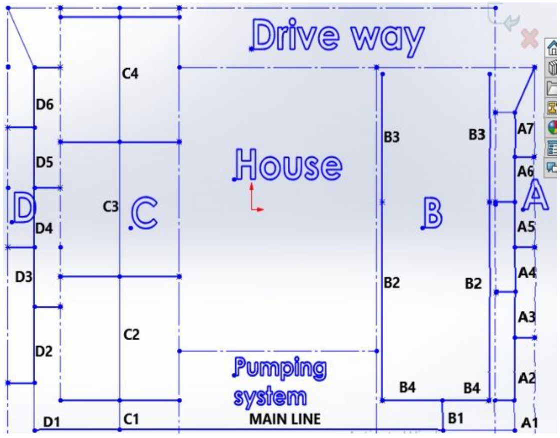

Figure 12. Pipeline network layout with pipe labels for identification

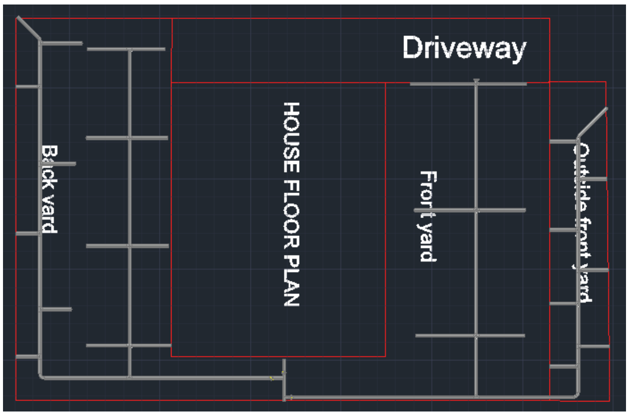

Figure 13. Preliminary Idea 1 for pipe layout for each zone, pipe networks consist of one supply pipe with branches that supply sprinklers.

Preliminary Idea 2

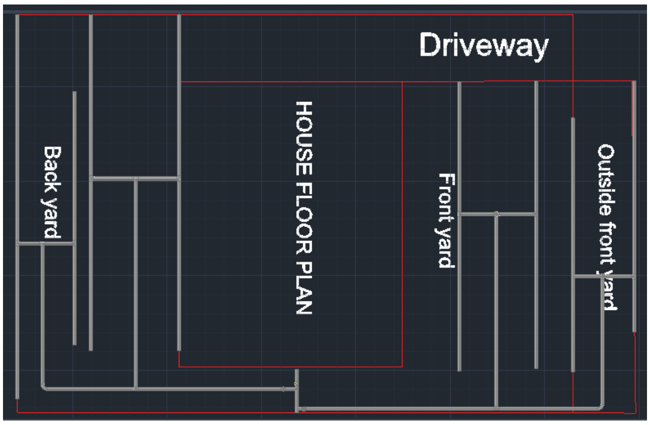

Figure 14. Preliminary Idea 2 for pipe layout for each zone. Pipes are arranged in an H shape.

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Pipeline sizes calculations

Assuming a maximum velocity not exceeding 1.5m/s inside the pipe to avoid water hammer.

Standard pipe sizes for PVC schedule 40 are going to be used refer to Annexure 5

Pipe sizes for branching pipes directly supplying emitters for zone A, C and D.

Zone A and D:

$V_{max} = 1.5m/s \quad Q = 0.30\ m3/h = 0.30\times\frac{1}{3600} = 8.333\times 10^{-5} m3/s$

$Q = Av \qquad A = \frac{\pi\times D^2}{4}$

$8.333\times 10^{-5} m3/s = \frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{7.07327\times 10^{-5}}$

$D = 8.4103\times 10^{-3} m = 8.4mm$

$v = 0.643m/s$

From PVC pipe chart use 15mm PVC.

Zone C:

$v = 1.5m/s \quad Q = 0.53\ m3/h = 0.53\times\frac{1}{3600} = 1.4722\times 10^{-4} m3/s$

$Q = Av \qquad A = \frac{\pi\times D^2}{4}$

$1.4722\times 10^{-4} m3/s = \frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{1.2496\times 10^{-4}}$

$D = 0.0118m = 11.18mm$

$v = 0.963m/s$

From PVC pipe chart use 15mm PVC.

Zone A and D use the same type sprinklers, therefore they will have the same pipe sizes.

For pipe D6 and A7

Both D6 and A7 have 2 sprinklers that require; $Q = 0.3\times 2 = 0.6m3/h$

$v = 1.5m/s \quad Q = 0.6\ m3/h = 0.6\times\frac{1}{3600} = 1.677\times 10^{-4} m3/s$

$Q = Av \qquad A = \frac{\pi\times D^2}{4}$

$1.6667\times 10^{-4} m3/s = \frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{1.4147\times 10^{-4}}$

$D = 0.01189m = 11.89mm$

$v = 0.963m/s$

From PVC pipe chart use 15mm PVC.

For pipe D5 and A6

Both D5 and A6 have 3 sprinklers that require: $Q = 0.3\times 3 = 0.9m3/h$

$v = 1.5m/s \quad Q = 0.6\ m3/h = 0.9\times\frac{1}{3600} = 2.5\times 10^{-4} m3/s$

$Q = Av \qquad A = \frac{\pi\times D^2}{4}$

$2.5\times 10^{-4} m3/s = \frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{2.1221\times 10^{-4}}$

$D = 0.01457m = 14.57mm$

$v = 1.286m/s$

From PVC pipe chart use 15mm PVC.

For pipe D4 and A5

Both D4 and A5 have 4 sprinklers that require: $Q = 0.3\times 4 = 1.2m3/h$

$v = 1.5m/s \quad Q = 1.2\ m3/h = 1.2\times\frac{1}{3600} = 3.333\times 10^{-4} m3/s$

$Q = Av \qquad A = \frac{\pi\times D^2}{4}$

$3.333\times 10^{-4} m3/s = \frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{2.8291\times 10^{-4}}$

$D = 0.0168m = 16.82mm$

$v = 1.097m/s$

From PVC pipe chart use 20mm PVC.

For pipe D3 and A4

Both D3 and A4 have 2 sprinklers that require; $Q = 0.3\times 5 = 1.5m3/h$

$v = 1.5m/s \quad Q = 1.5\ m3/h = 1.2\times\frac{1}{3600} = 4.1667\times 10^{-4} m3/s$

$Q = Av \qquad A = \frac{\pi\times D^2}{4}$

$4.16667\times 10^{-4} m3/s = \frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{3.5368\times 10^{-4}}$

$D = 0.018806m = 18.806mm$

$v = 1.28m/s$

From PVC pipe chart use 20mm PVC.

For pipe D2 and A3

Both D2 and A3 have 6 sprinklers that require; $Q = 0.3\times 6 = 1.8m3/h$

$v = 1.5m/s \quad Q = 1.8\ m3/h = 0.6\times\frac{1}{3600} = 5\times 10^{-4} m3/s$

Q = Av   A = $\frac{\pi\times D^2}{4}$

5×10^{-4}m3/s = $\frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{4.2441\times 10^{-4}}$

D = 0.0206m = 20.6mm

v = 1.4m/s

From PVC pipe chart use 20mm PVC.

For pipe D1 and A2

Both D1 and A2 have sprinklers that require; Q = 0.3 × 7 = 2.1m3/h

v = 1.5m/s   Q = 2.1 m3/h = $2.1\times\frac{1}{3600}$ = 5.833×10^{-4}m3/s

Q = Av   A = $\frac{\pi\times D^2}{4}$

5.8333×10^{-4}m3/s = $\frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{4.9515\times 10^{-4}}$

D = 0.02225m = 22.252mm

v = 1.128m/s

From PVC pipe chart use 25mm PVC.

For pipe A1

A1supplies 8 sprinklers that require; Q = 0.3 × 8 = 2.4m3/h

v = 1.5m/s   Q = 2.4 m3/h = $2.4\times\frac{1}{3600}$ = 6.677×10^{-4}m3/s

Q = Av   A = $\frac{\pi\times D^2}{4}$

6.6667×10^{-4}m3/s = $\frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{5.6588\times 10^{-4}}$

D = 0.02379m = 23.79mm

v = 1.241m/s

From PVC pipe chart use 25mm PVC.

Zone C and B use the same type sprinklers; therefore they will have the same pipe sizes.

For pipe B2 and C4

Both B2 and C4 have 2 sprinklers that require; Q = 0.53 × 2 = 1.06m3/h

v = 1.5m/s   Q = 1.06 m3/h = $1.06\times\frac{1}{3600}$ = 2.944×10^{-4}m3/s

Q = Av   A = $\frac{\pi\times D^2}{4}$

2.944×10^{-4}m3/s = $\frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{2.4993\times 10^{-4}}$

D = 0.0158m = 15.809mm

v = 0.914m/s

From PVC pipe chart use 20mm PVC.

For pipe C3

C3 have 4 sprinklers that require; Q = 0.53 × 4 = 2.12m3/h

v = 1.5m/s   Q = 2.12 m3/h = $2.12\times\frac{1}{3600}$ = 5.889×10^{-4}m3/s

Q = Av   A = $\frac{\pi\times D^2}{4}$

5.889×10^{-4}m3/s = $\frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{4.99864\times 10^{-4}}$

D = 0.0224m = 22.36mm

v = 1.128m/s

From PVC pipe chart use 25mm PVC.

For pipe B1 and C2

Both B1 and C2 have 6 sprinklers that require; Q = 0.53 × 6 = 3.18m3/h

v = 1.5m/s   Q = 3.18 m3/h = $3.18\times\frac{1}{3600}$ = 8.833×10^{-4}m3/s

Q = Av   A = $\frac{\pi\times D^2}{4}$

8.833×10^{-4}m3/s = $\frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{7.4979\times 10^{-4}}$

D =0.02738m = 27.382mm

v = 1.042m/s

From PVC pipe chart use 32mm PVC.

Main line and C1

Main line and **C1** have 8 sprinklers that require; Q = 0.53 × 8 = 4.24m^3/h

v = 1.5m/s   Q = 4.24 m^3/h = $4.24\times\frac{1}{3600}$ = $1.1778\times 10^{-3}m^3/s$

Q = Av   A = $\frac{\pi\times D^2}{4}$

$1.1778\times 10^{-3}m^3/s$ = $\frac{\pi\times D^2}{4}\times 1.5$

$\sqrt{D^2} = \sqrt{9.9973\times 10^{-4}}$

D = 0.01362m = 31.62mm

v = 1.305m/s

From PVC pipe chart use 32mm PVC.

For pipe B3

B3 has 1 sprinkler that require; Q = 0.53m^3/h

v = 1.5m/s Q = 0.53 m^3/h = 0.53× $\frac{1}{3600}$ = 1.4722× 10^{-4}m^3/s

Q = Av A = $\frac{\pi\times D^2}{4}$

1.4722× 10^{-4}m^3/s = $\frac{\pi\times D^2}{4}$ ×1.5

$\sqrt{D^2} = \sqrt{1.2496 \times 10^{-4}}$

D = 0.01118m = 11.18mm

v = 0.963m/s

From PVC pipe chart use 15mm PVC.

For pipe B4

B4 has 3 sprinklers that require; Q = 0.53 × 3 = 1.59m^3/h

v = 1.5m/s Q = 1.59 m^3/h = 1.59× $\frac{1}{3600}$ = 4.41667× 10^{-4}m^3/s

Q = Av A = $\frac{\pi\times D^2}{4}$

4.41667× 10^{-4}m^3/s = $\frac{\pi\times D^2}{4}$ ×1.5

$\sqrt{D^2} = \sqrt{3.74898 \times 10^{-4}}$

D = 0.01936m = 19.362mm

v = 1.463m/s

From PVC pipe chart use 20mm PVC.

Losses due to friction

Relative roughness (ε) = 3×10^{-7} m

Water properties from Annexure 4 for water at 20°C:

υ = 1.02×10^{-6}m^2/s η = 1.02×10^{-3}Pa•s ρ = 998 kg/m^3

velocity = 1.5m/s **γ** = 9.79×10^{3}N/m^3

For a 15mm PVC pipe;

ID = 16mm = 0.016m

$N_R = \frac{vD}{\upsilon} = \frac{1.5\times0.016}{1.02\times10^{-6}}$ = 23 529.4112

$\frac{D}{\varepsilon} = \frac{0.016}{3\times10^{-7}}$ = 53333.333

$$f = \frac{0.25}{\left[\log\left[\frac{1}{3.7\left(\frac{D}{\varepsilon}\right)}+\frac{5.74}{N_R^{0.9}}\right]\right]^2}$$

$$= \frac{0.25}{\left[\log\left[\frac{1}{3.7(53333.33)}+\frac{5.74}{23529.4112^{0.9}}\right]\right]^2}$$

= 0.02484

For a 20mm PVC pipe;

ID = 21mm = 0.021m

$N_R = \frac{vD}{\upsilon} = \frac{1.5\times0.021}{1.02\times10^{-6}}$ = 30882.3529

$\frac{D}{\varepsilon} = \frac{0.021}{3\times10^{-7}}$ = 70000

$$f = \frac{0.25}{\left[\log\left[\frac{1}{3.7\left(\frac{D}{\varepsilon}\right)}+\frac{5.74}{N_R^{0.9}}\right]\right]^2}$$

$$= \frac{0.25}{\left[\log\left[\frac{1}{3.7(70000)}+\frac{5.74}{30882.3529^{0.9}}\right]\right]^2}$$

= 0.0233

For a 25mm PVC pipe;

ID = 27mm = 0.027m

$N_R = \frac{vD}{\upsilon} = \frac{1.5\times0.027}{1.02\times10^{-6}}$ = 39 705.882

$\frac{D}{\varepsilon} = \frac{0.027}{3\times10^{-7}}$ = 90 000

$$f = \frac{0.25}{\left[\log\left[\frac{1}{3.7\left(\frac{D}{\varepsilon}\right)}+\frac{5.74}{N_R^{0.9}}\right]\right]^2}$$

$$= \frac{0.25}{\left[\log\left[\frac{1}{3.7(90000)}+\frac{5.74}{39705.882^{0.9}}\right]\right]^2}$$

= 0.0219

For a 32mm PVC pipe;

ID = 35mm = 0.035m

$N_R = \frac{vD}{\upsilon} = \frac{1.5\times0.035}{1.02\times10^{-6}}$ = 51 470.588

$\frac{D}{\varepsilon} = \frac{0.035}{3\times10^{-7}}$ = 116 666.667

$$f = \frac{0.25}{\left[\log\left[\frac{1}{3.7\left(\frac{D}{\varepsilon}\right)}+\frac{5.74}{N_R^{0.9}}\right]\right]^2}$$

$$= \frac{0.25}{\left[\log\left[\frac{1}{3.7(51470.588)}+\frac{5.74}{116666.667^{0.9}}\right]\right]^2}$$

= 0.02066

Total head losses per zone

Zone A

Total length of branches, L= 12.354m, v = 0.643m/s, D = 0.016m, f = 0.02484

$h_L = f\,\frac{L}{D}\,\frac{v^2}{2g} = 0.02484\,\frac{12.354}{0.016}\,\frac{0.643^2}{2\times9.81}$ = 0.404m

A7: L = 3m, v = 0.963m/s, f = 0.02484, D = 0.021m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.02484\frac{3}{0.016}\frac{0.963^2}{2\times9.81} = 0.220\text{m}$

A6: L = 3m, v = 1.286m/s, f = 0.02484, D = 0.016m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.02484\frac{3}{0.016}\frac{1.286^2}{2\times9.81} = 0.393\text{m}$

A5: L = 3m, v = 1.097m/s, f = 0.0233, D = 0.021m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0233\frac{3}{0.021}\frac{1.097^2}{2\times9.81} = 0.204\text{m}$

A4: L = 2m, v = 1.28m/s, f = 0.0233, D = 0.021m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0233\frac{2}{0.021}\frac{1.28^2}{2\times9.81} = 0.185\text{m}$

A3: L = 3m, v = 1.4m/s, f = 0.0233, D = 0.021m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.033\frac{3}{0.021}\frac{1.4^2}{2\times9.81} = 0.333\text{m}$

A2: L = 4.190m, v = 1.128m/s, f = 0.0219, D = 0.027m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0219\frac{4.190}{0.027}\frac{1.128^2}{2\times9.81} = 0.218\text{m}$

A1: L = 7.458m, v = 1.24m/s, f = 0.0219, D = 0.027m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0219\frac{7.458}{0.027}\frac{1.24^2}{2\times9.81} = 0.471\text{m}$

$$h_{L\,total} = 0.404 + 0.220 + 0.393 + 0.204 + 0.185 + 0.333 + 0.218 + 0.471 = \mathbf{2.428m}$$

Minor losses

$h_{L\text{ elbow}} = fK\frac{v^2}{2g}$ $K_{elbow} = 30f$ $K_{45\text{ elbow}} = 16f$

$K_{Tee} = 60f$ $K_{\text{globe valve}} = 340f$ f =0.02484

$h_{L\,elbow} = 0.02484 \times 30 \times \frac{1.5^2}{2\times9.81} = 0.0855\text{m}$

$h_{L\,7\,Tee} = 7 \times 0.02484 \times 60 \times \frac{1.5^2}{2\times9.81} = 1.196\text{m}$

$h_{L\,45\,elbow} = 0.02484 \times 16 \times \frac{1.5^2}{2\times9.81} = 0.0456\text{m}$

$h_{L\,minor\,losses}$ = 0.0855 + 1.196 + 0.0456 = 1.328m

$h_{L\text{ Zone A}} = h_{L\,minor\,losses} + h_{L\,total}$ = 1.328 + 2.428 = **3.755m**

Zone B

B3: L = 11.149×2 = 22.298m, v = 0.963m/s, f = 0.02484, D = 0.016m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.02484\frac{22.298}{0.016}\frac{0.963^2}{2\times9.81} = 1.636\text{m}$

B2: L = 11.149×2 = 22.298m, v = 0.914m/s, f = 0.0233, D = 0.021m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0233\frac{22.298}{0.021}\frac{0.914^2}{2\times9.81} = 1.053\text{m}$

B4: L = 4.5×2 = 9m, v = 1.463m/s, f = 0.0233, D = 0.021m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0233\frac{9}{0.021}\frac{1.463^2}{2\times9.81} = 1.089\text{m}$

B1: L = 2m, v = 1.042m/s, f = 0.02066, D = 0.035m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.02066\frac{2}{0.035}\frac{1.042^2}{2\times9.81} = 0.065\text{m}$

$$h_{L\,total} = 1.636 + 1.053 + 1.089 + 0.065 = \mathbf{3.843m}$$

Minor losses

$h_{L\text{ elbow}} = fK\frac{v^2}{2g}$ $K_{elbow} = 30f$ $K_{45\text{ elbow}} = 16f$

$K_{Tee} = 60f$ $K_{\text{globe valve}} = 340f$ f =0.02484

$h_{L\,2\,elbow} = 2 \times 0.02484 \times 30 \times \frac{1.5^2}{2\times9.81} = 0.170\text{m}$

$h_{L\,5\,Tee} = 5 \times 0.02484 \times 60 \times \frac{1.5^2}{2\times9.81} = 0.855\text{m}$

$h_{L\,minor\,losses}$ = 0.855 + 0.170 = 1.025m

$h_{L\text{ Zone B}} = h_{L\,minor\,losses} + h_{L\,total}$ = 1.025 + 3.843 = **4.868m**

Zone C

Total length of branches, L= 36m, v = 0.963m/s, D = 0.016m, f = 0.02484

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.02484\frac{36}{0.016}\frac{0.963^2}{2\times9.81} = 2.642\text{m}$

C4: L = 9m, v = 0.914m/s, f = 0.0233, D = 0.021m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0233\frac{9}{0.021}\frac{0.914^2}{2\times9.81} = 0.425\text{m}$

C3: L = 9m, v = 1.286m/s, f = 0.0219, D = 0.027m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0219\frac{9}{0.027}\frac{1.286^2}{2\times9.81} = 0.609\text{m}$

C2: L = 9m, v = 1.042m/s, f = 0.02066, D = 0.035m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.02066\frac{9}{0.035}\frac{1.042^2}{2\times9.81} = 0.294m$

C1: L = 2m, v = 1.305m/s, f = 0.02066, D = 0.035m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.02066\frac{2}{0.035}\frac{1.305^2}{2\times9.81} = 0.102m$

$h_{L\ total} = 2.642 + 0.425 + 0.609 + 0.102 + 0.294 = \mathbf{4.072m}$

Minor losses

$h_{L\ \mathrm{elbow}} = fK\frac{v^2}{2g}$ $K_{elbow} = 30f$ $K_{45\ elbow} = 16f$ $K_{Tee} = 60f$
$K_{globe\ valve} = 340f$ f =0.02484

$h_{L\ 2\ elbows} = 2 \times 0.02484 \times 30 \times \frac{1.5^2}{2\times9.81} = 0.171m$

$h_{L\ 3\ Tee} = 3 \times 0.02484 \times 60 \times \frac{1.5^2}{2\times9.81} = 0.513m$

$h_{L\ minor\ losses} = 0.171 + 0.513 = 0.684m$

$h_{L\ \mathrm{Zone\ C}} = h_{L\ minor\ losses} + h_{L\ total} = 4.072 + 0.684 = \mathbf{4.756m}$

Zone D

Total length of branches, L= 16.472m, v = 0.643m/s, D = 0.016m, f = 0.02484

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.02484\frac{16.472}{0.016}\frac{0.643^2}{2\times9.81} = 0.539m$

D6: L = 4m, v = 0.963m/s, f = 0.02484, D = 0.016m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.02484\frac{4}{0.016}\frac{0.963^2}{2\times9.81} = 0.294m$

D5: L = 4m, v = 1.286m/s, f = 0.02484, D = 0.016m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.02484\frac{4}{0.016}\frac{1.286^2}{2\times9.81} = 0.523m$

D4: L = 4m, v = 1.097m/s, f = 0.0233, D = 0.021m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0233\frac{4}{0.021}\frac{1.097^2}{2\times9.81} = 0.272m$

D3: L = 4m, v = 1.28m/s, f = 0.0233, D = 0.021m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0233\frac{4}{0.021}\frac{1.28^2}{2\times9.81} = 0.371m$

D2: L = 4m, v = 1.4m/s, f = 0.0233, D = 0.021m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.033\frac{4}{0.021}\frac{1.4^2}{2\times9.81} = 0.443m$

D1: L = 9.7m, v = 1.128m/s, f = 0.0219, D = 0.027m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.0219\frac{9.7}{0.027}\frac{1.128^2}{2\times9.81} = 0.510m$

$$h_{L\ total} = 0.539 + 0.294 + 0.523 + 0.272 + 0.371 + 0.443 + 0.510 = \mathbf{2.952m}$$

Minor losses

$h_{L\ \mathrm{elbow}} = fK\frac{v^2}{2g}$ $K_{elbow} = 30f$ $K_{45\ elbow} = 16f$ $K_{Tee} = 60f$
$K_{globe\ valve} = 340f$ f =0.02484

$h_{L\ 1\ elbows} = 0.02484 \times 30 \times \frac{1.5^2}{2\times9.81} = 0.085m$

$h_{L\ 5\ Tee} = 5 \times 0.02484 \times 60 \times \frac{1.5^2}{2\times9.81} = 0.855m$

$h_{L\ 45\ elbow} = 0.02484 \times 16 \times \frac{1.5^2}{2\times9.81} = 0.0456m$

$h_{L\ minor\ losses} = 0.0855 + 0.855 + 0.0456 = 0.986m$

$h_{L\ \mathrm{Zone\ D}} = h_{L\ minor\ losses} + h_{L\ total} = 0.986 + 2.952 = \mathbf{3.938m}$

Main pipe line

Total length of 32mm PVC pipes in the main pipe is 13m, v = 1.305m/s, f = 0.02066, D = 0.035m

$h_L = f\frac{L}{D}\frac{v^2}{2g} = 0.02066\frac{13}{0.035}\frac{1.305^2}{2\times9{,}81} = 0.666m$

Minor losses

$h_{L\ \mathrm{elbow}} = fK\frac{v^2}{2g}$ $K_{elbow} = 30f$ $K_{45\ elbow} = 16f$
$K_{Tee} = 60f$ $K_{globe\ valve} = 340f$ f =0.02484

$h_{L\ 3\ Tee} = 3 \times 0.02484 \times 60 \times \frac{1.5^2}{2\times9.81} = 0.513m$

$h_{L\ minor\ losses} = 0.513m$

$h_{L\ \mathrm{main\ pipe}} = h_{L\ minor\ losses} + h_{L\ total} = 0.513 + 0.666 = \mathbf{1.179m}$

From the above calculations we can see that Zone B has the highest head losses with 4.868m. Therefore I am going to use this value plus the head losses in the main pipe line system because only one zone is operated at a time and also the main pipeline system is always functional during the whole irrigation process.

Total head losses in the irrigation system = $h_{L\ main\ pipe} + h_{L\ Zone\ B}$ = 1.179 + 4.868 = **6.047m**

The sprinklers require 2 Bar for them to function; 2Bar = 2×10^5 Pa

$h = \frac{P}{\gamma}$ $\boldsymbol{\gamma} = 9.79\times10^3 N/m^3$ for water at 20°C

$h_{sprinkler} = \frac{2\times10^5}{9.79\times10^3} = 20.429m$

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Therefore the total head required by the system:

$H = h_{\text{sprinklers}} + h_{\text{total head losses}}$

$= 20.429 + 6.047$

$= \mathbf{26.476m}$

Simulation of Pipelines

The pipeline systems are going to be simulated using **PIPE FLO Professional**. Pipe Flo is a software that specializing in fluid flow inside pipes. Two different pipeline networks are going to be simulated using the same pump to determine or select the best pipe system for a specific zone.

Idea 1 For Zone A and D

Zone A and D

Aim:

To get a flow rate of 0.3m^3/hr at 2bar at emitter exit.

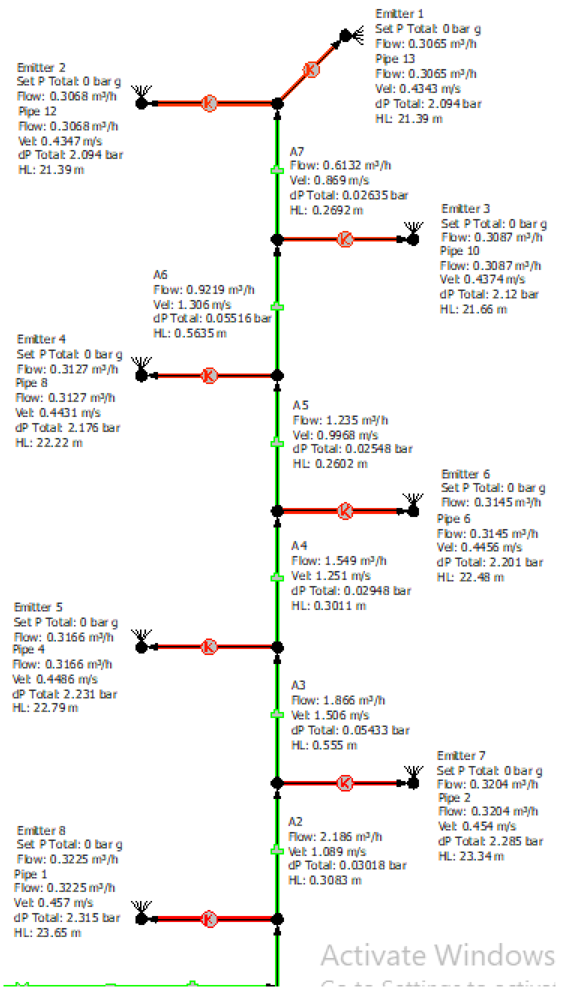

Figure 0–1 Zone A idea 1 simulation results

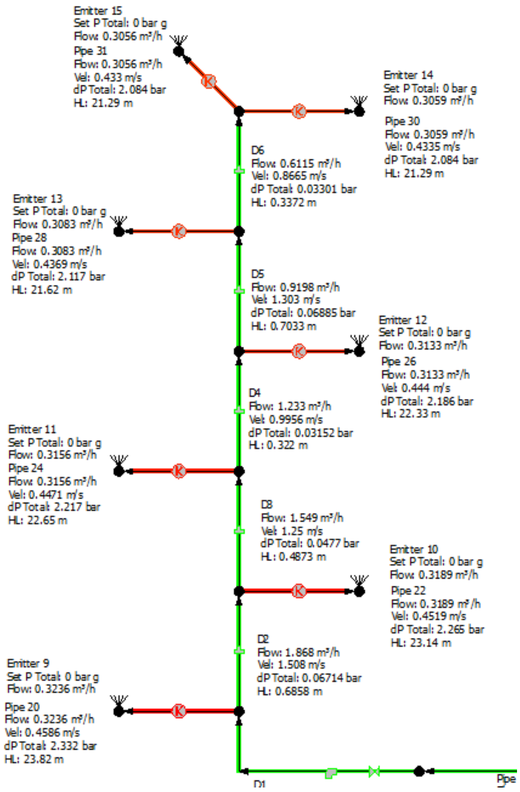

Figure 15. Zone D idea 1 simulation results

Idea 2 For Zone A and D

Zone A and D

Aim:

To get a flow rate of 0.3m^3/hr at 2bar at emitter exit.

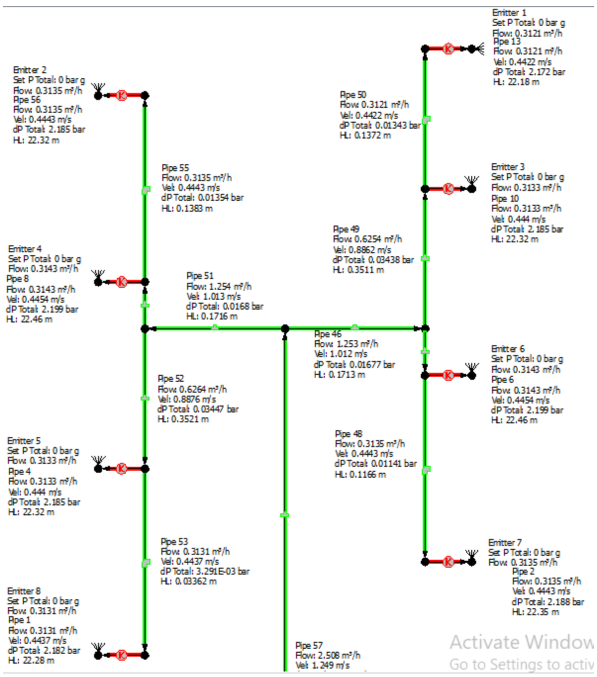

Figure 16. Zone A Idea 2 Simulation results

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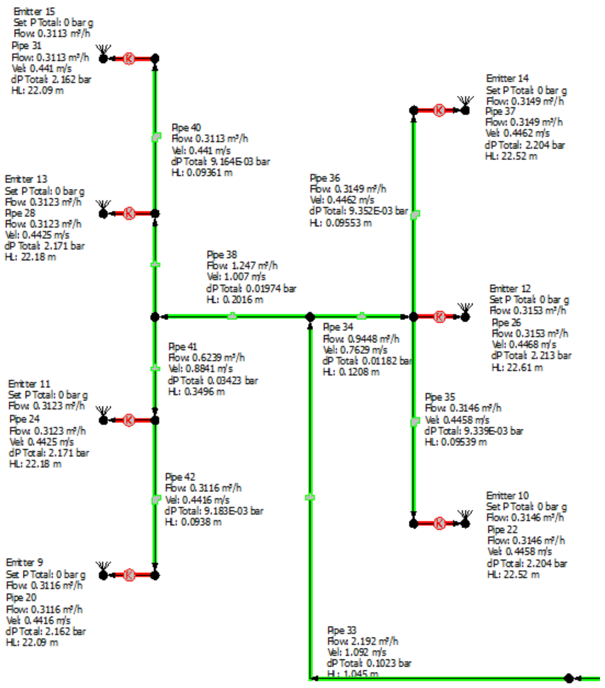

Figure 17. Zone D Idea 2 Simulation results

Idea 1 For Zone B

Zone B

Aim:

Zone B has emitters that require a flow rate of atleast 0.53 m3/hr at 2 bar each.

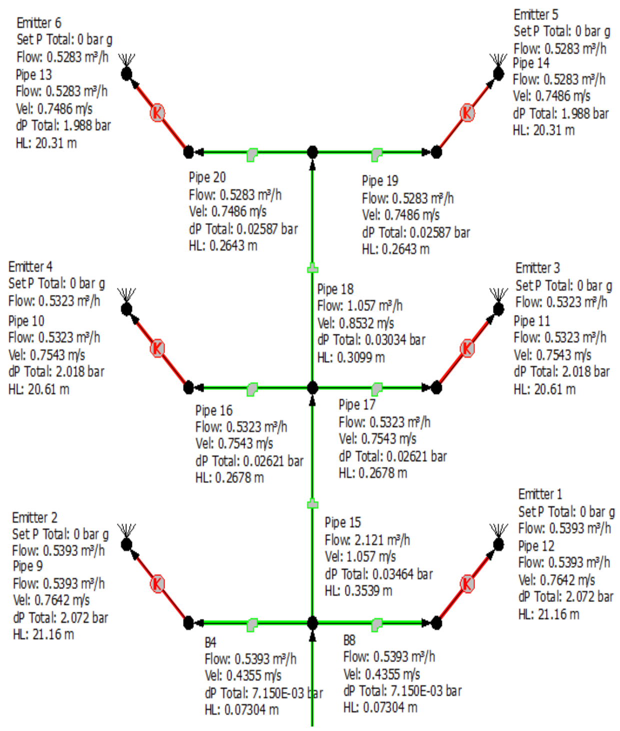

Figure 18. Zone B Idea 1 Simulation results

Idea 2 For Zone B

Zone B

Aim:

Zone B has emitters that require a flow rate of atleast 0.53 m3/hr at 2 bar each.

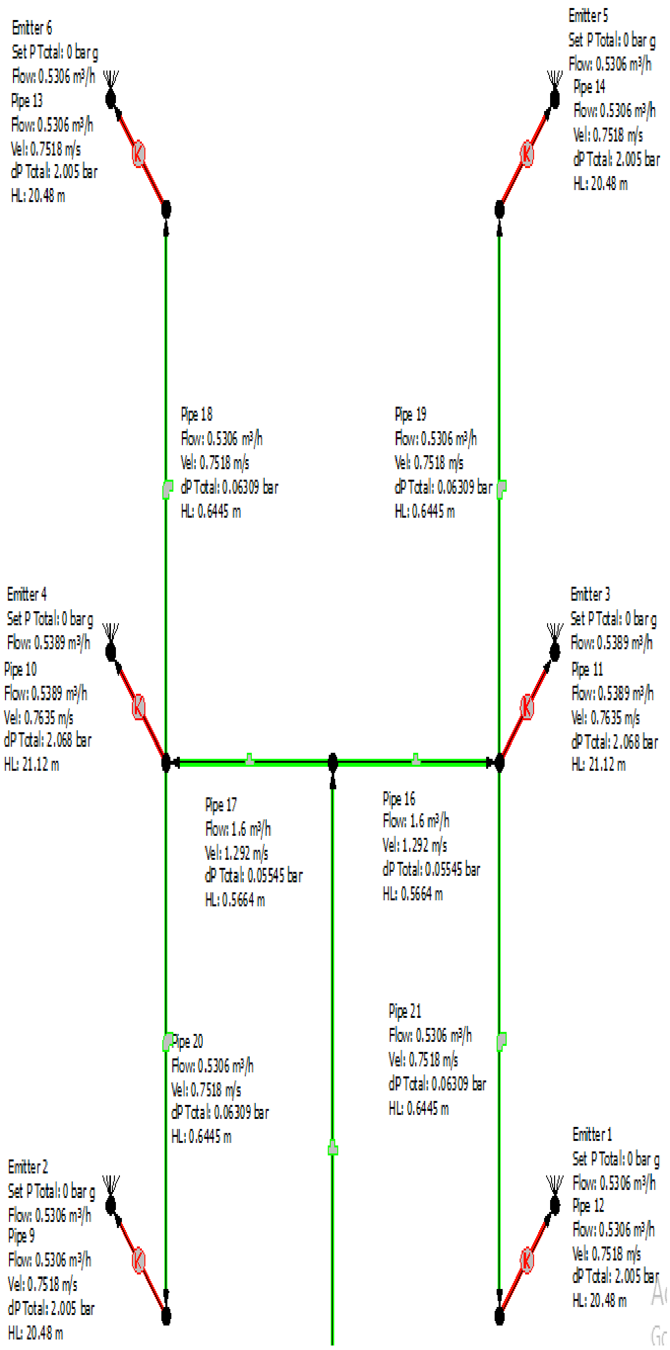

Figure 19. Zone B Idea 2 simulation results

Idea 1 For Zone C

Zone C

Aim:

Zone C has emitters that require a volume flow rate of at least 0.53 m^3/hr at 2 bar each.

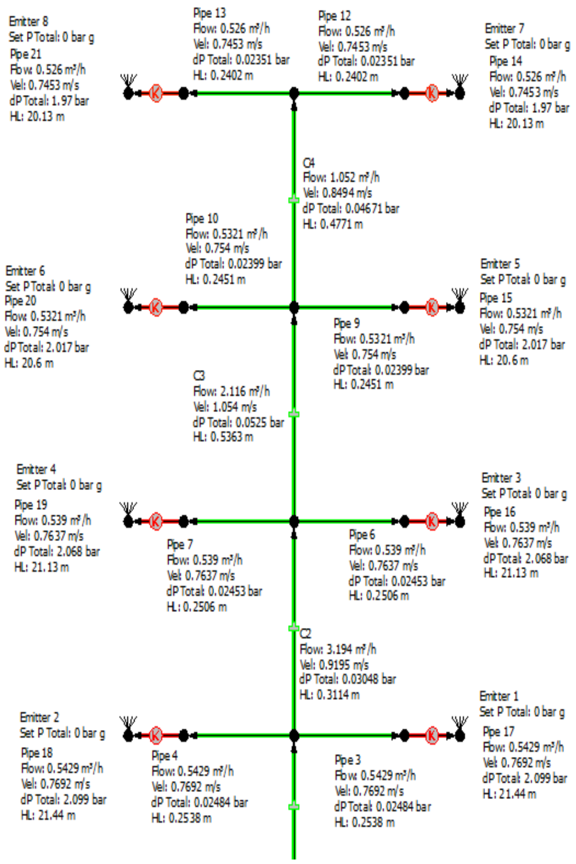

Figure 20. Zone C idea 1 simulation results

Idea 2 For Zone C

Zone C

Aim:

Zone C has emitters that require a volume flow rate of at least 0.53 m3/hr at 2 bar each.

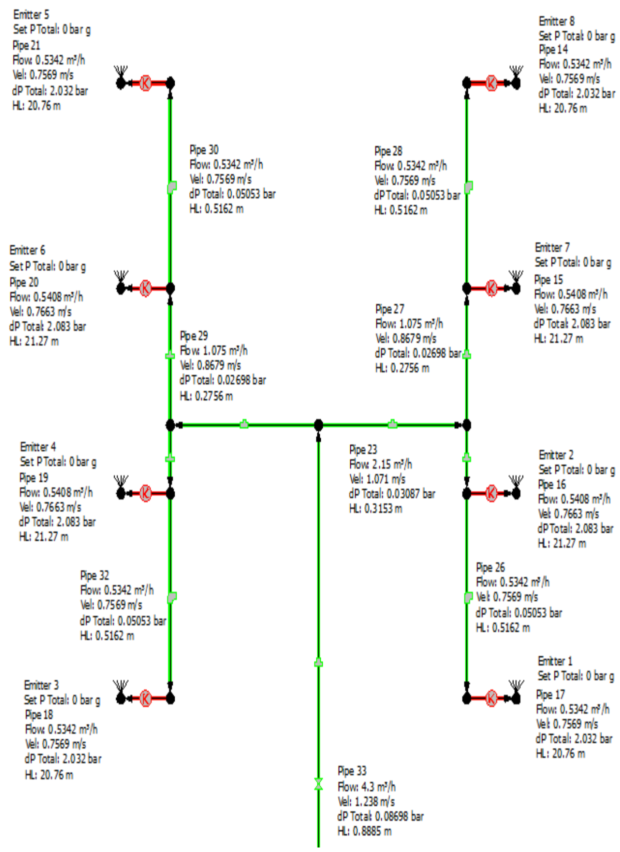

Figure 21. Zone C idea 2 simulation results

CONCLUSION

The main aim of the current study is to design an irrigation pipeline system that will deliver the right pressure and flow rate required during. To achieve this different designed study of irrigation system was theoretically modelled and their pressure and flow rate investigated. Different irrigation performance were revealed. The system with the best pipeline network for the irrigation system was revealed in the current study. The system gave the best possible irrigation during operation. The required pressures and the volume of flow rate during operation were acceptable.

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REFERENCE

[1] Dorota Z. Haman and Fedro S. Zazueta, 2017. *University of Florida IFAS extension.* [Online] Available at: https://edis.ifas.ufl.edu/wi005#IMAGE%20WI:WI005E2A [Accessed 22 April 2020].

[2] Easygardenirrigation, 2020. *Easygardenirrigation.* [Online] Available at: https://www.easygardenirrigation.co.uk/pages/garden-irrigation-planning-guide-starter [Accessed 1 April 2020].

[3] Fanie Vorster, ARC Institute for Agricultural Engineering, 2016. *Agricultural Research Council.* [Online] Available at: http://www.arc.agric.za/arc-iae/News%20Articles%20Library/Irrigation%20system%20design.pdf [Accessed 1 April 2020].

[4] Group, L. G., 2020. *Life Green Group.* [Online] Available at: http://www.lifegreengroup.co.za/life-landscapes/irrigation-sprinkler-systems/[Accessed 3 April 2020].

[5] Institute, S. A. L., 2017. *SALI.* [Online] Available at: https://www.sali.co.za/index.php/about-sali/blog/the-six-types-of-irrigation-systems [Accessed 2 April 2020].