System Analysis of Portable Water Shortage in the Mpumalanga Province of South Africa

Motsi Ephrey Matlakala and Daramy Vandi Von Kallon
Mechanical Engineering Department
University of Johannesburg
Johannesburg, South Africa
motsiephrey@gmail.com, dkallon@uj.ac.za

Abstract

The challenge of water shortages is affecting a lot of areas in South Africa especially rural areas. The government have introduced different strategies to deal with the problem. Amongst the areas in South Africa, Mpumalanga Province is one of the areas that struggles with water shortages. An investigation is conducted to address the water crisis and present solutions from the System Analysis. The issues of the budget were addressed to assist with the allocation of funds that will help the communities. The effective pumping systems strategic management are also addressed in this study to assist management to maintain the leaking and burst pipes. The commercial steel is the material of the pipe used for the pumping system. The calculations of the pumping system were carried out to help with improving of the system based on the demand that arises with the increase of the population. The pumping system curves were plotted at different length of the system to improve the head while the flow rate is kept at constant.

Keywords
Pumping System, Cost, System Analysis, Material and Head.

1. Introduction
The cause of the water supply problem in Mpumalanga is first due to the lack of facilities to accommodate the demand of water in communities. Most communities are facing the challenge of being supplied with undrinkable water and having to find means of cleaning the water themselves, this is mainly because of poor maintenance of the supply systems. Due to poor maintenance of the water supply system water supply does not meet the demand for water in the communities [1, 2]. The inability to meet the water demand and population growth in the communities has caused some members of the community to make their undocumented pipeline connections for their homes from the main supply. This has affected the water pumping system whereby the system is at risk of being damaged due to increased load which surpasses the designed system load. For years municipalities have been known to mismanage resources from road maintenance to water supply system maintenance lines [3, 4]..

The lack of resources and capital has led to shortages of water and poor infrastructure. Another budget constrain is due to corruption, this illegal act has cost communities their livelihoods whereby awarded tenders are not completed in the given time or not completed at all. Cheaper and untested materials are used which leads to a collapse of the infrastructure. The facilities are not provided with water cleaning chemical [5]. On heavy rainy days the water obtained from boreholes and other sources is brown. For those that cannot afford cleaning equipment they have to wait for the dirt to sink before they can use the water. The municipalities employ unqualified people to save funds, this has led to the theft of some equipment. The problem being investigated in this paper is the water supply shortage caused by the overloading of the pumping system. The investigation aims at designing a pumping system that will be able to meet the water supply demand of the communities to prevent illegal connection in the mainline.

2. System Analysis Approach for Water Shortage Solution

The challenge of water services investigated through system analysis in this study involves the process analysis which covers the operation philosophy of the pumping systems, the engineering design, maintenance and cost analysis. The system analysis of the water services is done through the engineering design by varying the length of the pumping system to satisfy the demand of water supply to the communities in Mpumalanga. In this study, the design of the pumping system is done at different pipe lengths to consider future demand for water related to the increase of the population in the study area. The maintenance and operation of the pumping systems help with preventing unplanned damages in the systems that can result in the shortage of water supply. The cost analysis is also taken into consideration to analyses the risk and viability of the pumping system and infrastructure are not maintained

2.1 Cost Analysis

The cost analysis in this project involves the cost for the tenders to carry out the projects, commissioning, and handing over projects of water supply. The budget is estimated based on the overall budget allocated to the study area. It is concluded here that it is less costly to use the resources the municipalities have than to outsource resources. It is, therefore, important that there should be budget allocated for training of employees to be able to maintain and operate the pumping systems in the study area.

2.2 Maintenance and Operation

The planned maintenance is suitable to keep the pumping systems up and running. The planned maintenance has preventive and corrective maintenance which both require shutdown for them to take place especially. To avoid failure of operation of the plant, it is important to have a standby pump in case the other needs serious maintenance or overhauling needs to take place. Furthermore, the shutdown is normally taking place at the point where there is less demand to avoid the disturbance of operation to reach the required demand [2].

2.3 Material Selection

Selecting the right sizing of the pipes for the pumping systems is a critical component to the success of any project for water supply. Equally important is selecting construction materials. The initial cost of these materials is normally the first consideration [4, 6]. Operational costs, replacement costs and longevity of service and repair costs will, however, determine the actual cost of the pump during its lifetime. A suitable material is chosen based on application criteria. For most water and other noncorrosive services, commercial steel material satisfies these criteria for the pipe lines [3, 4].

3. Design of Pumping System

The design of the pumping system is done based on the length of the pipe to monitor the flow capacity and the head. This is done to analyze the flow and head of water capacity being supplied to the community over the years while the population increases. The calculations were carried out by assuming the pumping system to have a constant pipeline diameter of 0.3 m. The different lengths of 45m and 60m were assumed to improve the head and flow rate of the water. The calculations were carried out using the flow rates of 0.05 m^3/s to 0.6 m^3/s stepped by 0.05 m^3/s intervals, to calculate the total head of the system for each flow rate and each pump system, at different length of the pipe.

3.1 Sample of Calculations for Pump System 1and 2

Pipe diameter, $D = 0.3$ m
The flow rate of water that is used is,

$Q = 0.6\ m^3/s.$

Length of the pipe, $L = 45$ m, 60 mm

Static head, $H_s = 30$ m

Commercial steel pipe roughness, $\varepsilon = 0.045$ mm

Kinematic viscosity, $\nu = 1.787 \times 10^{-6} \mathrm{m}^2/\mathrm{s}^2$.

3.2 The Total Head at the Length of Pipe = 45mm

The cross-sectional area of the pipe:

$$A = \frac{\pi D^2}{4} \qquad 3.1$$

$$= \frac{\pi(0.3)^2}{4}$$

$$= 0.0707\ \mathrm{m}^2$$

The velocity of fluid inside the pipe:

$$V = \frac{\dot{Q}}{A} \qquad 3.2$$

$$= \frac{0.6}{0.0707}$$

$$= 8.4866\ \mathrm{m/s}$$

Reynold's Number:

$$Re = \frac{VD}{\nu} \qquad 3.3$$

$$= \frac{(8.4866)(0.3)}{(1.787 \times 10^{-6})}$$

$$= 1\,424\,723$$

Reynold's number is greater than 4000, which implies that the water flow in the pipe is turbulent.

Darcy friction factor:

$$f = \frac{0.25}{\left[\log\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{Re^{0.9}}\right)\right]^2} \qquad 3.4$$

$$= \frac{0.25}{\left[\log\left(\frac{(0.045 \times 10^{-3})}{3.7(0.3)} + \frac{5.74}{(1424723)^{0.9}}\right)\right]^2}$$

$$= 0.0139$$

Friction Head:

$$H_f = \frac{fLV^2}{2Dg} \qquad 3.5$$

$$= \frac{(0.0139)(45)(8.4866)^2}{2(0.3)(9.81)}$$

$$= 7.6538\ \mathrm{m}$$

Velocity Head:

$$H_v = \frac{V^2}{2g} \qquad 3.6$$

$$= \frac{(8.4866)^2}{2(9.81)}$$

$$= 3.6709 \text{ m}$$

Total pump system head for 0.6 m^3/s:

$$H_T = H_s + H_f + H_v \quad 3.7$$

$$= 30 + 7.6538 + 3.6709$$

$$= 41.32 \text{ m}$$

3.3 The Total Head at the Length of Pipe = 60mm

The cross-sectional area of the pipe:

$$A = \frac{\pi D^2}{4} \quad 3.8$$

$$= \frac{\pi(0.3)^2}{4} = 0.0707 \text{ m}^2$$

The velocity of fluid inside the pipe:

$$V = \frac{\dot{Q}}{A} \quad 3.9$$

$$= \frac{0.6}{0.0707}$$

$$= 8.4866 \text{ m/s}$$

Reynold's Number:

$$Re = \frac{VD}{\nu} \quad 3.10$$

$$= \frac{(8.4866)(0.3)}{(1.787 \times 10^{-6})}$$

$$= 1\,424\,723$$

Reynold's number is greater than 4000, which implies that the water flow in the pipe is turbulent.

Darcy friction factor:

$$f = \frac{0.25}{\left[\log\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{Re^{0.9}}\right)\right]^2} \quad 3.11$$

$$= \frac{0.25}{\left[\log\left(\frac{(0.045 \times 10^{-3})}{3.7(0.3)} + \frac{5.74}{(1424723)^{0.9}}\right)\right]^2}$$

$$= 0.0139$$

Friction Head:

$$H_f = \frac{fLV^2}{2Dg} \quad 3.12$$

$$= \frac{(0.0139)(60)(8.4866)^2}{2(0.3)(9.81)}$$

$$= 10.2050\text{m}$$

Velocity Head:

$$H_v = \frac{V^2}{2g} \qquad 3.13$$

$$= \frac{(8.4866)^2}{2(9.81)}$$

$$= 3.6709 \text{ m}$$

Total pump system head for 0.6 m^3/s:

$$H_T = H_s + H_f + H_v \qquad 3.14$$

$$= 30 + 10.2050 + 3.6709$$

$$= 43.88 \text{ m}$$

The flow rate used is 0.6 m^3/s at a different length. The same procedure was applied to all flowrates at a different length. The final results are summarized in tables 1 and 2.

4. Results

The calculations were carried out at different flowrates and varying the length of the pumping system from 35m, 45m, 60m and 70m to determine the total head in the system but only calculations at 45m and 60m length of the system are shown in details in this paper, see tables 1 and 2. The pumping systems have bending which causes losses in the system. The focus in this paper is on the major losses which were calculated through friction head. The results of the calculations are summarised in tables 1 and 2.

Table 1: Pumping System Calculation Results of System 2 with a Pipe Length of 45m and a diameter of 0.3m.

flow rate,	**Velocity, V**	**Reynold's Number, Re**	**Darcy friction factor, f**	**Total Head of the system,**
/s	m/s	-	-	m
0.05	0.7072	118724.12	0.0182	30.10
0.1	1.4144	237448.24	0.0164	30.35
0.15	2.1216	356172.36	0.0156	30.77
0.20	2.8289	474913.26	0.0151	31.33
0.25	3.5361	593637.38	0.0148	32.05
0.30	4.2433	712361.50	0.0145	32.91
0.35	4.9505	831085.62	0.0144	33.95
0.40	5.6577	949809.74	0.0142	35.11
0.45	6.3649	1068533.84	0.0141	36.43
0.50	7.0721	1187257.97	0.0140	37.90
0.55	7.7793	1305982.09	0.0140	39.56
0.60	8.4866	1424723.00	0.0139	41.32

Table 2: Pumping System Calculation Results of System 3 with a Pipe Length of 60 m and a diameter of 0.3m.

flow rate,	Velocity, V	Reynold's Number, Re	Darcy friction factor, f	Total Head of the system,
/s	m/s	-	-	m
0.05	0.7072	118724.12	0.0182	30.12
0.1	1.4144	237448.24	0.0164	30.44
0.15	2.1216	356172.36	0.0156	30.95
0.20	2.8289	474913.26	0.0151	31.64
0.25	3.5361	593637.38	0.0148	32.53
0.30	4.2433	712361.50	0.0145	33.58
0.35	4.9505	831085.62	0.0144	34.85
0.40	5.6577	949809.74	0.0142	36.26
0.45	6.3649	1068533.84	0.0141	37.89
0.50	7.0721	1187257.97	0.0140	39.67
0.55	7.7793	1305982.09	0.0140	41.72
0.60	8.4866	1424723.00	0.0139	43.88

5. Discussion

From the results obtained in Section VI, a graph was plotted, see figure 1. The trends of the graph are between the different length for the pumping systems. It can be observed that the head from pumping system 1 to pumping system 4 increases with the increase of the length. The pumping systems 1-4 were obtained at different length of the pipe vary at 35m, 45m, 60m and 70m to monitor the total head. At a flow rate of 0.05 m^3/s all pumping systems has the same total head of 30m because is at the starting point of all the systems with the lowest flow rate of 0.05 m^3/s which does not have influence on the total head. There is gradually of increase of head verse pumping system because the pipes with long distance it means greater the total head. As the length of the pumping system increases, more power will be required to overcome the pressure drops in the system. It means the operation cost and material cost of the pump will rise due to the increase of the pipe length. For this reason, Commercial Steel is chosen as a material to be used because is strong, accessible and affordable.

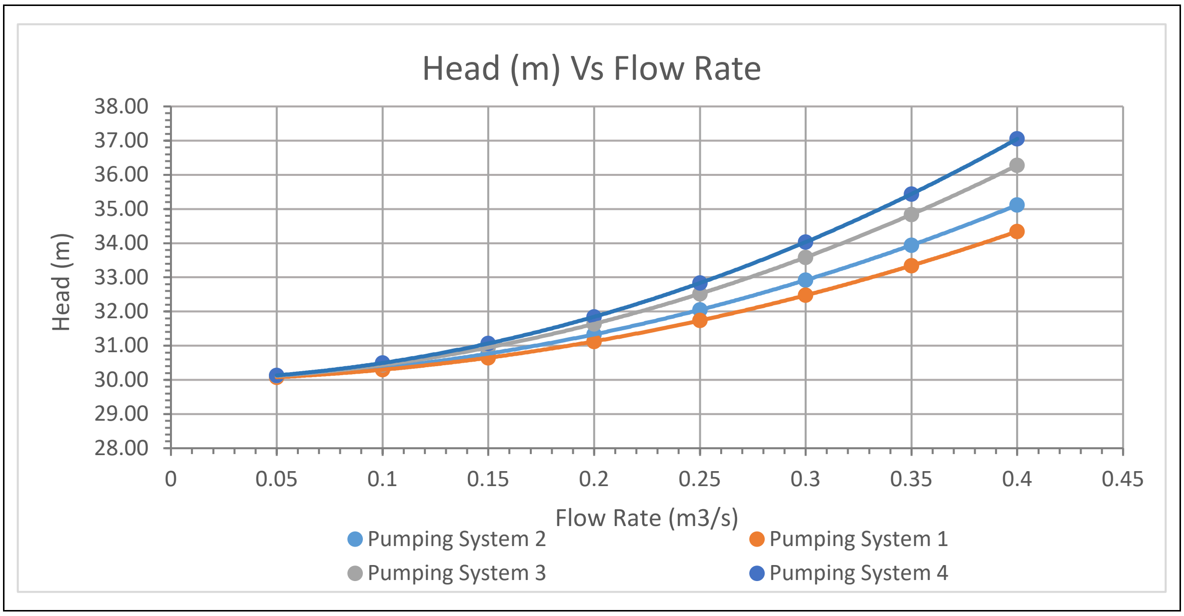

Figure 1: Total Head Vs Flow rate Curve for Pumping Systems 1, 2, 3 and 4.

6. Conclusion

From the results obtained, the issue of water services in Mpumalanga can be solved and managed through the system analysis. The municipalities in the study area should take into consideration the population rate so that the water systems can be upgraded accordingly. To meet the requirement of the system, the total dynamic head is used. Dynamic head means there is a change of the pressures, velocities, elevations and friction losses when the system and the pump are in operation [8]. The total head was calculated at different length of 35m, 45m, 60m and 70m of the pumping system to monitor the total head. The results were summarised in tables 1 and 2. The trends of the graph in figure 1 was then obtained. It was observed (see figure 1) that the length of the pumping system at the same flow rate increases the head of the system. Therefore, the improvement of the system can be obtained by increasing the length of the system to meet the demand for water supply.

7. References

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8. Biographies

Mr Motsi Ephrey Matlakala is a South African holder of a M-Tech in Mechanical Engineering from the University of Johannesburg. Mr Matlakala is currently working as a Mechanical Engineering Graduate at Rand Water Zuikerbourch Pumping Station since June 2017. During his Masters studies, He published five (5) papers and was also selected as a reviewer of paper in two (2) conferences, locally and internationally. Mr Matlakala is preparing to enrolling PhD in Mechanical Engineering with the University of Johannesburg. Mr Matlakala is a member of South African Institute of Mechanical Engineering SAIMECH and Candidate Technologist with ECSA. Mr Matlakala's primary research areas are System Analysis and Dynamics, Optimization, Computational Fluid Dynamics, Finate Element Analysis and Water Research.

Dr Daramy Vandi Von Kallon is a Sierra Leonean holder of a PhD degree obtained from the University of Cape Town (UCT) in 2013. He holds a year-long experience as a Postdoctoral researcher at UCT. At the start of 2014 Dr Kallon was formally employed by the Centre for Minerals Research (CMR) at UCT as a Scientific Officer. In May 2014 Dr Kallon transferred to the University of Johannesburg as a full-time Lecturer and later a Senior Lecturer in the Department of Mechanical and Industrial Engineering Technology (DMIET). Dr Kallon has more than twelve (12) years of experience in research and six (6) years of teaching at University level, with industry-based collaborations. He is widely published, has supervised from Masters to Postdoctoral and has graduated seven (7) Masters Candidates. Dr. Kallon's primary research areas are Acoustics Technologies, Mathematical Analysis and Optimization, Vibration Analysis, Water Research and Engineering Education.