



Optimization of the Water Reticulation System at Bulawayo Mining Company (BMC), Zimbabwe

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ABSTRACT

Bulawayo Mining Company (BMC) is estimated to lose millions of dollars in potential profit over a period of its documented life of mine (LOM) which is nine years as at May 2019. The projected loss is attributed to the time value of money emanating from the extension of the Life Of Mine due to mining inefficiencies. These inefficiencies are due to poor management of the water management system that plays a key role in the mining cycle. This project was done to make a quantitative analysis of BMC underground water management system in order to establish the bottlenecks and use this knowledge to optimize an efficient Water Reticulation System (WRS). Erratic water supply has an implication of disrupting the mining cycle as most of the operations rely on water; therefore, the supply of water is of great significance. In an effort to resolve the problem of erratic water supply, experiments were conducted to ascertain the quantity of water demanded in contrast with the supply. New Visual basic computer program (WaterCal) that can calculate the optimum WRS parameters as well as simulating real conditions through extrapolation was developed. Algorithm based on fluid mechanics laws and theorems was integrated in the application thereby simplifying the mine design and planning process. It was strongly recommended that the mine should consider using computer solutions in future designs of Water Reticulation Systems such as the WaterCal Windows Application. The pipe size is supposed to be increased from 50mm to 100mm. The mine should also adopt the use of flow meters and pressure gauges to effectively monitor and control the reticulation system effectively.

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1. INTRODUCTION

Mining entails the extraction of minerals containing rock from the host rock [1]. Conventionally it follows a cycle of the drill, blast, load and hauls [2]. When engineers design any mining operation, the aspects key to the success of the project lies in safety and profitability [3]. To maximize profits, costs are reduced to the most feasible and lowest value. Therefore, it is paramount to look into each activity in the mining cycle and ensure efficiency and effectiveness [4]. One of the auxiliary services keys to mining is the supply of water which is used for several purposes, but not limited to drilling, waterblast, washing down, separating minerals from waste, dust suppression,

cleaning equipment, drinking water and sanitary supplies, and for conveying tailings and concentrate [5]. Without water, the mining cycle stops because drilling cannot commence [6]. Also, the safety of workers is compromised when water is not used to allay dust [7].

Mines encounter production losses due to water shortages caused by dry underground dams or significantly low water levels in the dam. During fire-fighting operations, similar shortages have been experienced [8]. The water shortages are attributed to small pipe diameters carrying water from the underground dams to the end users. The smaller the pipe size, the less the pipe's carrying capacity, hence a reduced water

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supply [9]. However, the main cause of water shortages has been pinpointed as the deficiency in proper designing of the dams as well as the exit pipe from the dam. If this is not efficiently designed, the water distribution is affected, resulting in an unplanned and undesirable water flow [10].

Proper design of the Water Reticulation System (WRS) will result in the uninterrupted water supply to all sections, thereby bringing efficiency. Profitability can then be achieved through a proper water management system. Currently, not much research has been done to optimize underground WRS, and as a result, there is no known method of designing underground water supply systems. Technology has simplified engineering designs in different fields therefore, there is a gap

in creating software to design water systems in underground mines. The aim of this study is to compute design parameters which satisfy the water demand through the development of a Windows software.

2. MATERIALS AND METHODS

The study area in this research is Bulawayo Mining Company (BMC). BMC is located in the south-eastern part of Bulawayo, approximately 35 km from the central business district. It is connected well to the city by a major road surfaced with asphalt and linked to local communities through secondary gravel roads. Fig. 1 shows the study area.

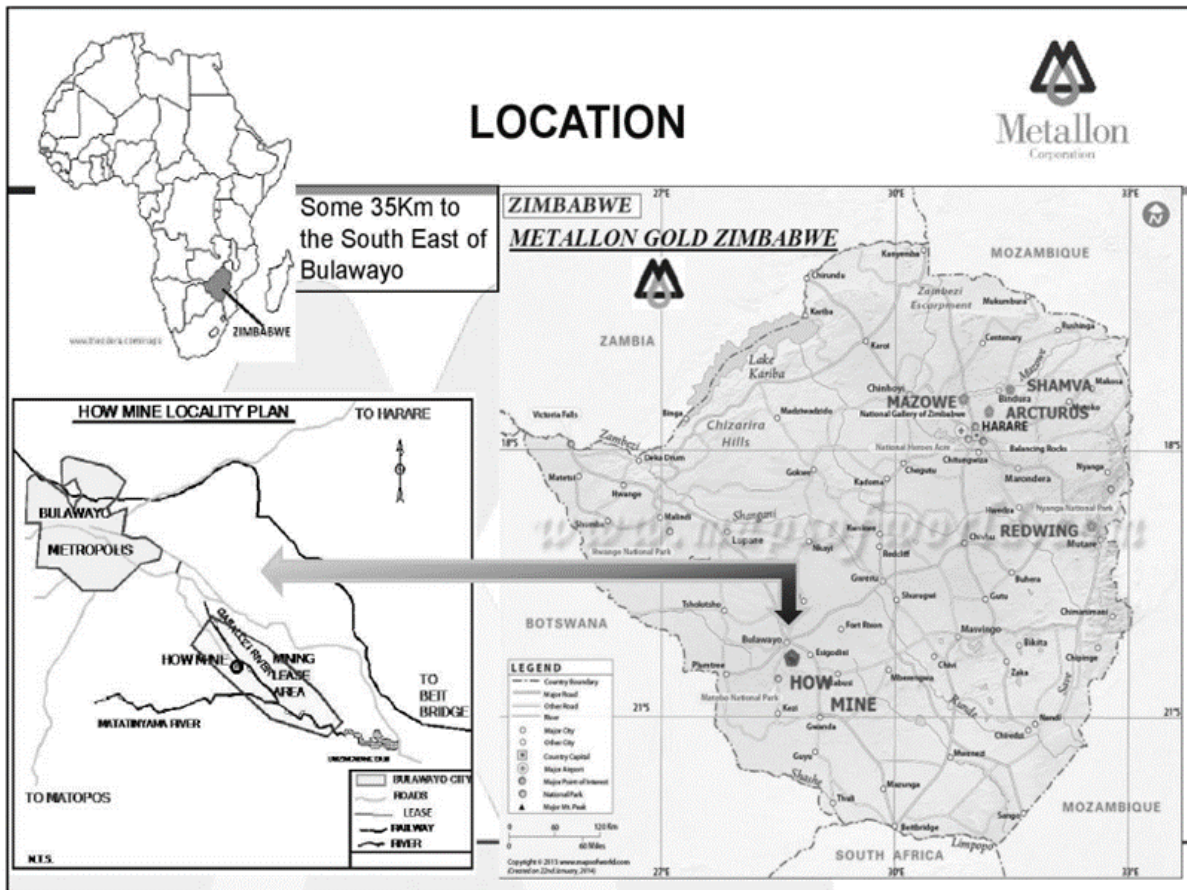


Fig 1. Geographic Location of Bulawayo Mining Company.

The initial phase of the research involved gleaning the company documents and maps. Water pressure was measured using pressure gauges, and the flow rate was determined using the Purdue trajectory method [11]. In addition, an estimated flow rate was measured by assessing the time taken to fill a 200 liters drum. The drilling rate i.e. the time taken to drill primary ends, secondary ends and stopes. In addition, a pump analysis was performed, and details of the capacities were obtained against an efficiency output of 70% due to their old ages and repairs over the years.

The peak load was determined using the following equation

$$Peak\ load = Maximum\ Demand \times Time \quad (1)$$

A critical aspect for sizing any Water Reticulation System was determining the water demand. The components necessary

for this task are jackhammer s215/ s25 (Mindrill, South Africa) , s36 konkola (Mindrill, South Africa), kemp u3-9b (HUD Mining Suppliers, South Africa), watering down, water blast, and quantifying leaks.

A visual basic program (WaterCal) was created so that any designer without engineering knowledge in the construction of a gravity flow water system could design a Water Reticulation System. The dams are all set at the height of 3 m due to height limitations underground.

The market has fixed pipe sizes of 13 mm, 25 mm, 50 mm, 100 mm and 150 mm [12]. These pipe sizes can be inputted on WaterCal, and other variables can be calculated. The designer can then analyze if other parameters can be met; if not, the pipe size is changed until the design parameters are found.

The dam's outflow rate must be high enough to equal the maximum water demanded in a day. Calculations were done to find the minimum source flow rate to fulfil these conditions. The supply throughout the day should be more than the demand to be able to supply continuous flow. Any flow rate below that minimum will provide intermittent flow. Surge capacity was designed using a head of 1 meter above the minimum allowable head, and the pumping rate was determined using the peak demand.

$$Pumping\ Rate = Peak\ Demand \quad (2)$$

To help the mine planners of Water Reticulation System in the future, an analysis of dam sizing that would be needed, depending upon the demand, was completed. The mine can use this model when the funds, manpower, and materials are available. To size the water storage dams, the first demand needs to be projected for the last year of the design life of the storage dam. This projection can be found in the long-term mining plan. Once a projected demand is found, the average daily water can be calculated. Maximum daily water demand is determined by multiplying with a safety factor of 1.2.

$$Q_{max} = Q_{ave} \times 1.2 \quad (3)$$

Where

Q_{max} = Maximum daily usage

Q_{ave} = Average daily usage

Water will most likely be demanded in a shorter time, as most drilling operations use water for hours out of a twenty-four-hour day. Thus, it would be good to design the dam for those peak flow conditions using a peaking factor which tells us how many times greater than our maximum daily demand will be. The equation used was:

$$Q_{peak} = Q_{drillmax} \times 1.2 \quad (4)$$

Where

$Q_{drillmax}$ = Maximum demand during drilling session

Q_{peak} = Peak demand

To get the surface area of the dam, we take the peak demand in cubic meters and divide it by a height of 1 meter above the minimum allowable head. This will give a dam that can supply continuous flow even if the users demand peak flow for the entire estimated peak time.

$$A_{dam} = \frac{Q_{peak}(m^3)}{1} \quad (5)$$

Where

A_{dam} = Area of the dam (m^2)

3. RESULTS

The mine water requirements per day are shown in table 1.

Table 1: Water requirements

Machine	Number of machines	Total requirement (l/min)	Duration (hours/day)	Quantity (l/day)
Jackhammer s215/ s25	6	36	4	51840
S36 konkola	36	7	6	90720
Kemp u3-9b	36	4	6	51840
Washdown	6	17	0.5	3060
Waterblast	3	17	4	12240
Total	87	81	20.5	209700
Corrected demand (using a contingency factor of 1.2)				251640

3.1. Purdue trajectory method

A graph was plotted of the head against the velocity, and it was observed that they have a direct relationship. The velocity

increases with an increase in the head, therefore, the head in the dam is a critical factor to consider.

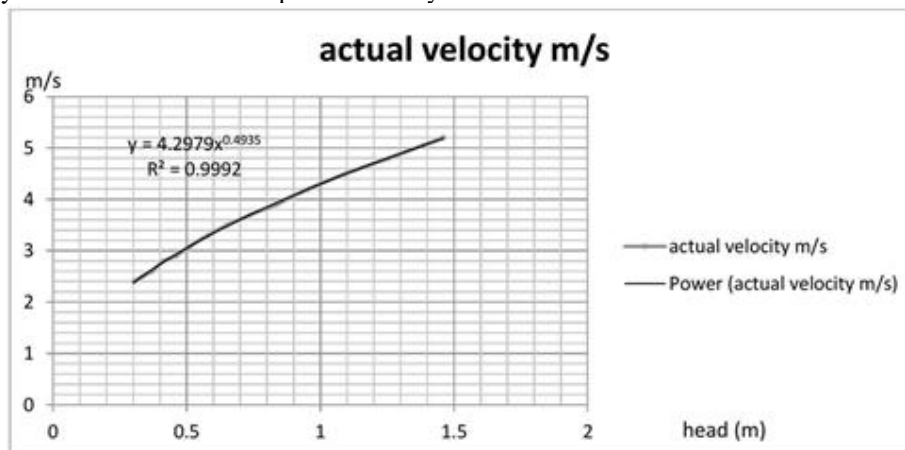


Fig 1: Relationship between head and actual velocity.

Increasing the height of water in the dam according to Torricelli's theorem $V = \sqrt{2gh}$ will increase the discharge velocity [13]. This can be achieved by increasing the pumping

capacity of mono-pumps such that water levels remain above the minimum allowable head. Table 2 shows the pumps that are currently being used.

Table 2: Pump sizes

Level	Pump Sizes	Volume Range (m ³ /Hr)	Volume Range (l/Min)	Maximum Head	Motor Size	Dam Size (m ³)
28	D70BH100D	6-18	100-300	150M	15 Kw/20 Hp	60
26	D70BH250D	15-60	250-1000	150M	35 Kw/40 Hp	55
23	D70BH100D	6-18	100-300	150M	15 Kw/20 Hp	53
20	D70BH100D	6-18	100-300	150M	15 Kw/20 Hp	60
14						100
14						120
14						150
14						175

Table 2 shows that except for 26 L all other stations have pumps with a capacity lower than that of a peak demand which is 734.41/min.

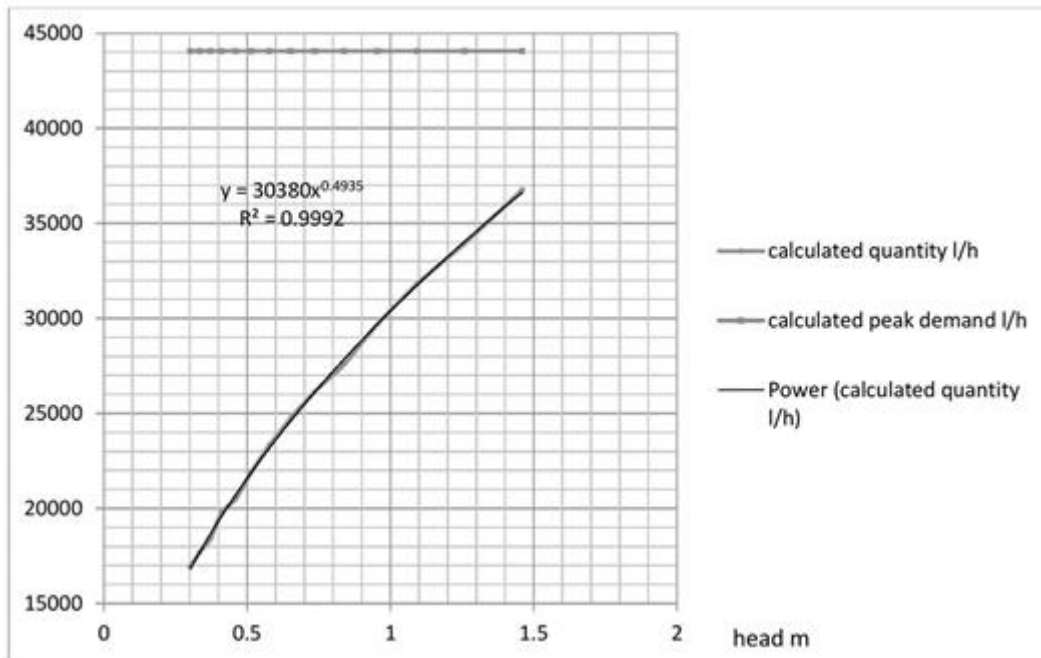


Fig 3: Demand vs Supply Graph.

3.2. Leakages

Table 3 shows that leakages on an average result in losses of approximately 5.4 liters per minute.

Table 3: Leakages

Leakage	Level	Orebody	Time (min)	Quantity	Flowrate (l/min)	Day	Leakages	Total flowrate (l/min)
1	28 L	400 N	20	20	1	1	10	10
2	28 L 10	350 N	25	20	0.8	2	4	3.2
3	28 L 20	320 N	28	20	0.714285714	3	6	4.28571486
4	27 L	300 N	24	20	0.833333333	4	3	2.5
5	27 L	300 N	23	20	0.869565217	5	9	7.826086957
Average			24	20	0.843436853		6.4	5.397995859

Low water supply is due to various factors, among which are low discharge rate from the dam, small pipe diameters and leakages. Therefore, leakages should be mended timeously to increase the quantity of water, and either velocity or pipe area, or both should be increased [14].

3.3. Area increase

The surface area of the machine pipe column has been reduced by material clogging in the pipe. This is caused by the fact that all settler dams are full or almost full with mud. This will result in the mud going down the machine column, and then

it will be trapped by rust on horizontal parts of the pipe column, thereby forming a bed which will slow the movement of water while simultaneously reducing the pipe carrying capacity. Therefore, it is paramount that de-mudding be done as soon as possible to allow mud to settle without getting into the pipes again. The pipe size should be increased to 100 mm.

3.4. Velocity Increase

According to the Torricelli theorem, increasing the dam's water height will increase the discharge velocity [13]. This can be achieved by pumping mono pumps' capacity so that water levels remain 1 meter above the discharge pipe. The dams should be constructed in such a manner that the excavation

gives a headroom that allows the dam wall to be greater than 1 meter above a minimum allowable head.

3.5. WaterCal Model

WaterCal was developed to aid in the optimization of the Bulawayo Mining Company Water Reticulation System. Fig. 4 is one of the snippets of the application which were used to find the optimum design parameters.

The initial phase of the research involved gleaning the company documents and maps. Water pressure was measured using pressure gauges. The flow rate was determined using the Purdue trajectory method [11].

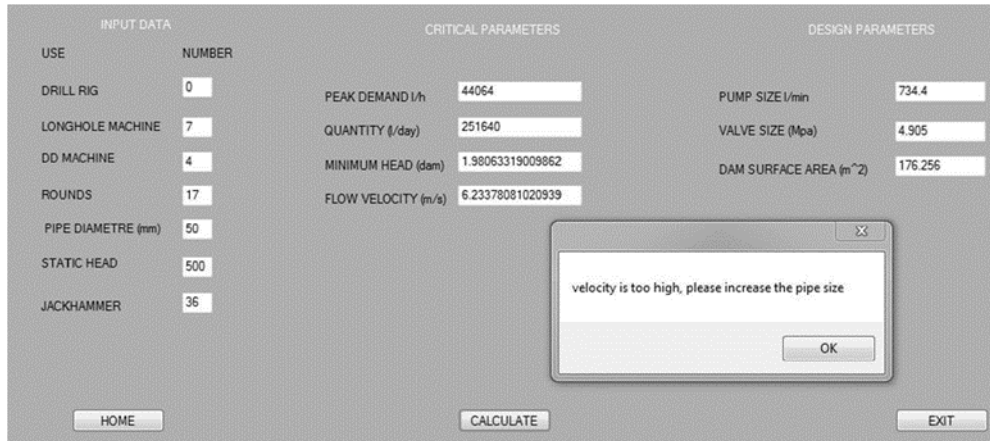


Fig 4: WaterCal system design.

The calculations in Figure 4 performed by WaterCal established certain relationships between head, quantity and velocity, as shown in the Fig. 5.

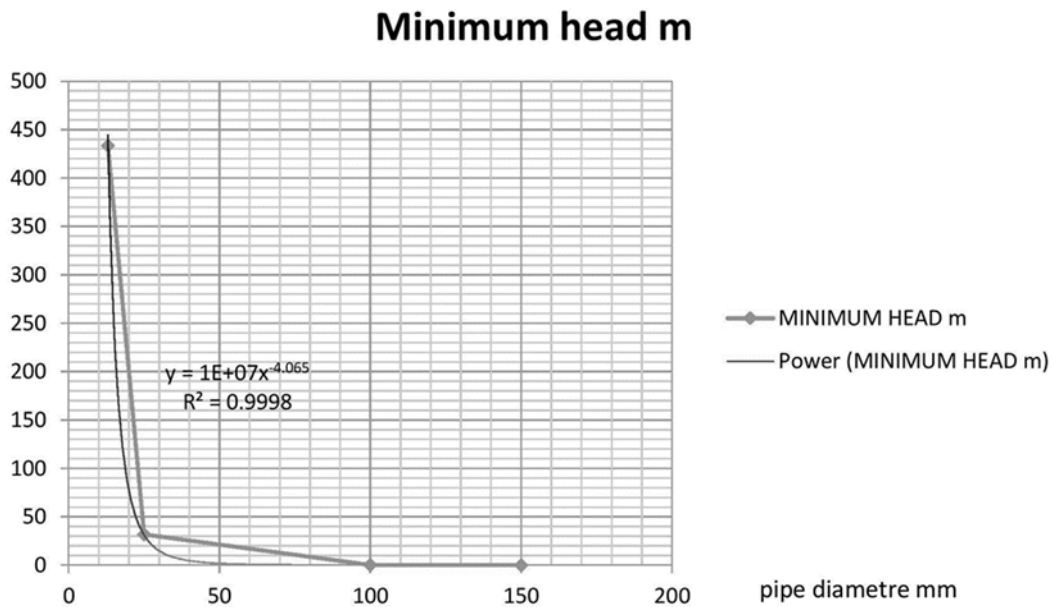


Fig 5: Head-Diameter Relationship.

Fig. 5 shows that the minimum head greatly decreases when pipe size is changed from 13 mm to 25 mm. from 25 mm there is a significant decrease in change in head. However, there

is a slight decrease in the head when the pipe diameter is increased from 10 mm to 150 mm.

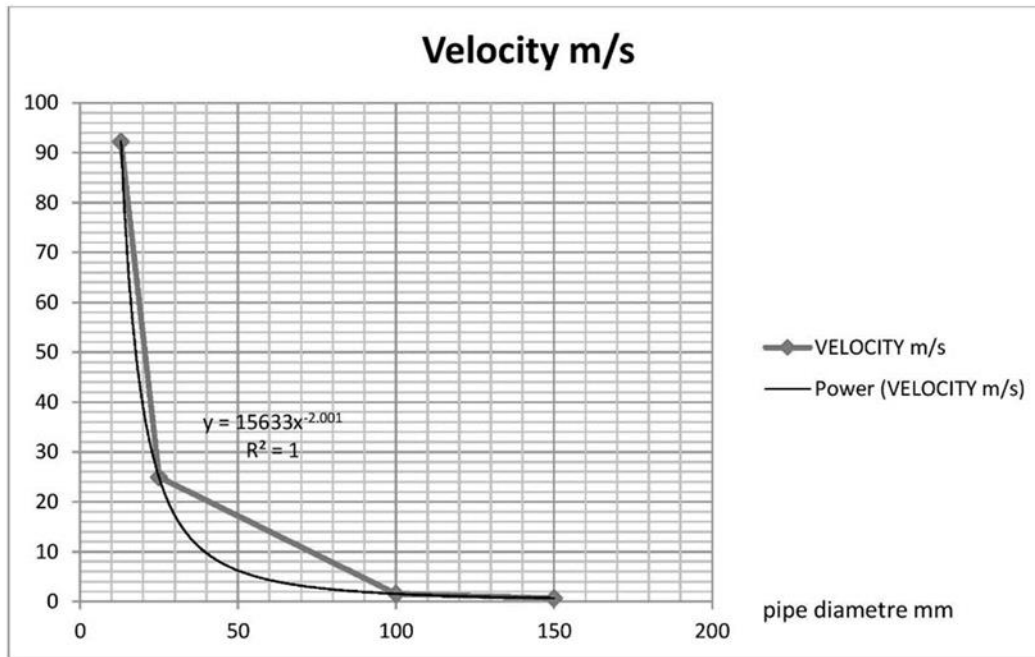


Fig 6: Velocity-Diameter Relationship.

Fig. 6 shows that the minimum velocity greatly decreases when pipe size is changed from 13 mm to 25 mm. From 25 mm to 50 mm there is a significant decrease in the change in head. However, there is a slight decrease in the head when the pipe diameter is increased from 100 mm to 150 mm. Fig. 5 and Fig. 6 were superimposed on each other and showed an interesting relationship, as shown in Fig. 7. The two graphs merge at a pipe diameter of 100 mm, making them an important and critical pipe diameter.

Table 4: WaterCal discrepancy table

Head (m)	Actual Velocity (m/s)	WaterCal Velocity (m/s)	% Discrepancy
1.46	5.2	5.344	-2.694610778
1.26	4.8	4.969	-3.401086738
1.09	4.5	4.632	-2.849740933
0.96	4.2	4.329	-2.97990298
0.84	3.9	4.054	-3.798717316
0.74	3.7	3.804	-2.733964248
0.65	3.5	3.577	-2.152641879
0.58	3.3	3.37	-2.077151335
0.52	3.1	3.18	-2.51572327
0.46	2.9	3.006	-3.526280772
0.41	2.8	2.845	-1.58172232
0.37	2.6	2.698	-3.632320237
0.33	2.5	2.561	-2.38188077
0.30	2.4	2.435	-1.437371663
\bar{x}			-2.697365468

4. DISCUSSIONS

The Purdue trajectory method was used to figure out the flow velocity of water in the pipeline in relation to the water level in the dam. This information was then used to calculate the supply capacity of the system. To verify the results from the Purdue trajectory method, another technique was implemented using a drum, and the results were similar. The results were plotted on an excel graph and compared with the peak demand, and it was found that the supply was greatly lower than the maximum demand. An independent technique was developed through software solutions resulting in the development of a windows application (WaterCal). The application was coded

Table 4 shows discrepancies that were observed between the actual velocity and the WaterCal velocity. The discrepancies result from a low dam discharge velocity due to the effect of vena contracta (constriction of fluid flow from dam to discharge pipe) where there is loss of energy, Energy losses due to frictional losses, and WaterCal assumes ideal conditions.

using Visual Basic 2010, integrating the equations formulated from the basic physics of the fluid flow. It was observed that the peak demand of 44 064 l/h was never achieved by the varying water supply, which depended on the water level in the dam. From the research, it was evident that no model is being followed in distributing underground water thereby, the system is bound to fail.

5. CONCLUSIONS

The factors that govern WRS were pipeline size, level of water in the dam, dam size, pumping rate, and demand. For a given constant quantity of water in the pipe, the size of the pipe determines the velocity of water within the pipe. Therefore, the quantity of water flowing in the pipe is limited when the velocity is maintained within the prescribed limits of laminar flow. The bigger the pipe size, the more the water flows in the system, but there is a point where an increase in pipe size has an insignificant impact on the other parameters of the system thereby, to avoid unnecessary costs an optimum pipe size should be used. The size of pump plays an important role in maintaining the level of water in the dam above the minimum allowed head so as to meet the required demand. When the pump is delivering water into the dam at a rate equal or above the discharge rate it implies that the system will never fail because the required head will be maintained.

From the analysis of the BMC WRS, it was noted that there is no documented model which is being used to supply water to

different sections. As a result, it is inevitable not to have uninterrupted water supply. Pinpointing of problems is a mammoth task when there is no schematic to follow thereby more time is wasted in trying to troubleshoot. The experimental results revealed that the water flow was following a hydraulic model in which there is a direct relationship between the head of water in the dam and the flow rate. As demand greatly varies depending with the time of the day, it is of great importance to factor in the peak period of the day. As production schedules differ from time to time, demand today will be different with demand tomorrow therefore careful planning should be done taking into consideration the maximum expected demand within the prescribed LOM limits. Whenever there is high dam drawdown, the flow rate drastically reduces. The study unveiled the fact that the water demand is greater than the supply therefore water shortages are bound to happen every day. The 2 inch sized pipeline is too small to carry the required quantity of water within prescribed velocity limits. Leakages were found to be having insignificant impact to the shortage of water. In order to maintain the head of water in the dam above the allowed minimum level, it was found that the available pumps are smaller than the required pump size of 750l/min. In this project new WRS as well as a new Visual basic program (WaterCal) that can calculate the optimum WRS was developed. By controlling the system water reticulation parameters, efficiency will be realized. WaterCal software proved to be effective in simulating the flow of water in pipes therefore it can be used to design an optimized WRS. This section is not mandatory but can be added to the manuscript if the discussion is unusually long or complex. Purdue trajectory method was used to figure out the flow velocity of water in the pipeline in relation to the level of the water in the dam.

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