Hydrology & Hydraulics Engineering

Civil Engineering | *The City University of New York*

PUMP SYSTEM DESIGN

Project Report for Requester

JEngineers PLLC

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EXECUTIVE SUMMARY

JEineers PLLC is providing the co-op director, Reza Khanbilvardi, of a new NYC Township, with a pumping system design. We provide a site plan, a pump station, a pipe network, and an elevated water tower solution for the residents of the township. The water must be transferred from a 10-meter-deep reservoir to one or more elevated water towers. The towers are designed to hold water for 16 hours/day, but the pumping system is designed to run for both 8hours/day and 16 hours/day, for a total of 350 days a year. The first criteria designed was a system with a flow rate of 145 L/s for the low demand and 224L/s for the high demand months. Four pumps (No. 4, 3250 RPM) will be placed in parallel and then in series with each other at the pump station. The pipes used to connect the pumps inside the pump station were neglected in all calculations made. The system uses 195 meters of pipe with three 90-degree elbows and a gate valve. The calculations for the required head were obtained by assuming an elevation of 36 meters on the delivery side, which resulted in a static lift of 36 meters. This is the difference between the total energy at the base of the water tower and the total energy at the top of the reservoir. Using the designed flow rate mentioned above, we obtained a surplus of 1,118,398.80 gallons of water. In order to store this water, two storage tanks were chosen and placed in series. One of the storage tanks will have a water capacity of 1-million-gallons, the second tank will have a water capacity of 125,000 gallons of water. The Multi-Column Tanks provide the perfect choice because they are capable of holding our water capacity.

The initial cost of the pump and pipe installation will be $8,307.98. If cost of energy consumption remains the same and the pumps run at full capacity with both systems for high and low demand, the total cost of energy use per year will be $59,448.34. Seeing that the tanks are large, we had to contact several providers to get quotes. We continue to wait on these quotes. This is our preliminary cost analysis and we will send the updated analysis once we obtain the quotes and determine the most cost effective and operational tank options provided to us.

INTRODUCTION

JEngineers PLLC is excited to take on the challenge presented by the co-op director, Reza Khanbilvardi, of a new NYC Township. The director is looking for professional engineers that can design a pumping system that will pump water from a 10-meter-deep supply reservoir to a water tower 35 meters above the ground in the town. The reservoir is located a considerable distance away and will require a 195m long pipeline network. The director requires that 75 meters of pipeline and one 90° elbow be placed on the suction side of the pump station, also 120 meters of pipeline, three 90° with R/D= 2.0 elbows and a gate valve and a check valve must go on the delivery side of the pump station. The system must be designed to operate 350 days a year. Neither the pipe size or pump combinations have been specified, they have been left for the engineers to decide. However, the director emphasizes that he wants the optimum design. If the system is designed to operate for 8 hrs/day instead of 16 hrs/day we have been asked to design a storage tank.

OBJECTIVE

Our goal for this project is to present Mr. Khanbilvardi with the optimum design that he is looking for. We want to create a pipe network that will support the design flow rate and give us enough head to get the water to the tower. We want to minimize the cost of the pipe network by trying to use the smaller sized pipes. However, our primary goal is to deliver enough water to the water tower to support the demand in the town, this means that there is a possibility that we might need to utilize larger and more costly pipes. We will look at all options and pick the best one. We understand that the water demand is high and that we will need more pumps to meet that demand. We look to build a pump station of at least four pumps placed in parallel and in series. The pumps' flow capacity, efficiency, cost and operation will drive our design options. In the end, we want to provide our client with the most efficient, reliable, flexible, and affordable pump system. The tank will be designed to hold the maximum surplus of water left behind during the months where water consumption is low. This will allow the town to use the water in the tank to compensate for any shortages during the months of high consumption.

SITE DESCRIPTION

The site is located on a flat piece of land. There is a 10-meter-deep water reservoir carved into the ground, 9 meters of pipeline will go into the reservoir, leaving an approximate 1 meter between the bottom of the reservoir and the suctioning pipe. A 90° elbow will be placed at the top of the reservoir and will connect to a second piece of pipe that will go directly to the pump station. The pump station will be placed above ground; It will be located 64 meters to the right of the reservoir. Having the pump station above ground will allow technicians and engineers access to the pumps in case of an emergency or malfunction. On the delivery side, we have chosen to place the pipes underground. We do not want our pipes to be above ground because it is not safe to have exposed pipe running for that long. The pipe will be placed 2 meters below ground and will include three 90° bends. For our design, we decided to have our pipeline go up a 1 million gallon water tower. The pipe will rise 35 meters above the ground to meet the bottom of the tank. The gate valve will be placed 1 meter above the ground on the delivery side, right underneath the water tower. In addition, because we have an excess in surplus, we were required to have another 125,000 water tower. Figure 1 and 2 are a visual representation for our design(not drawn to scale).

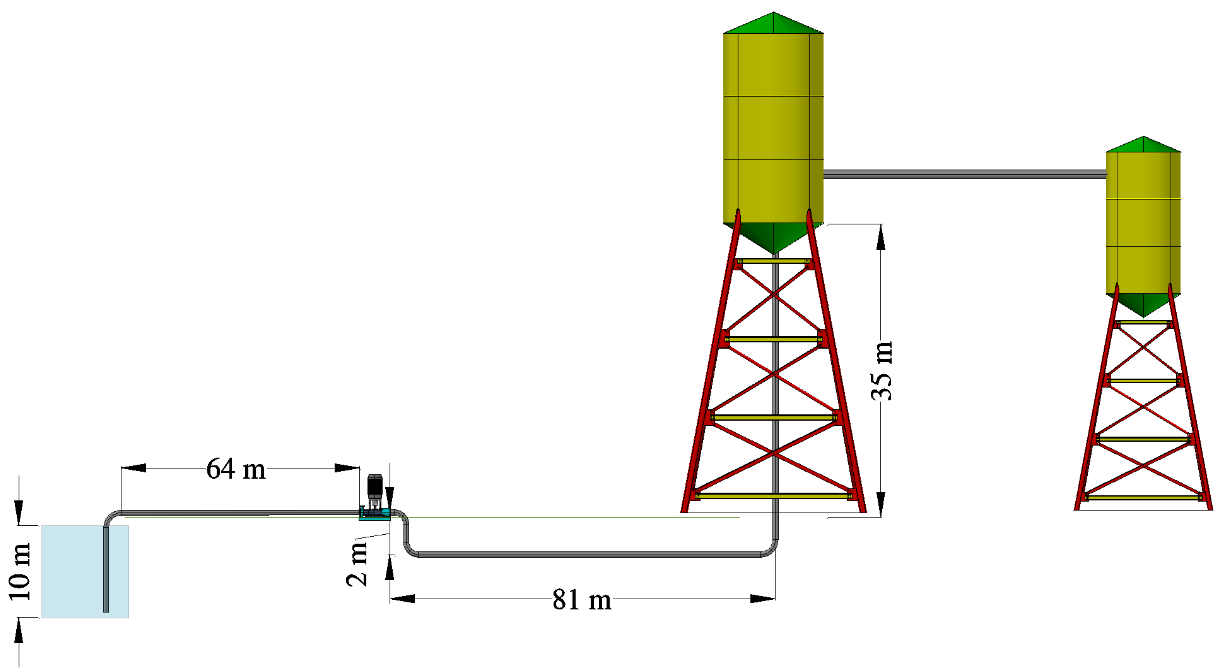

Figure 1: Front View of Pump System Design

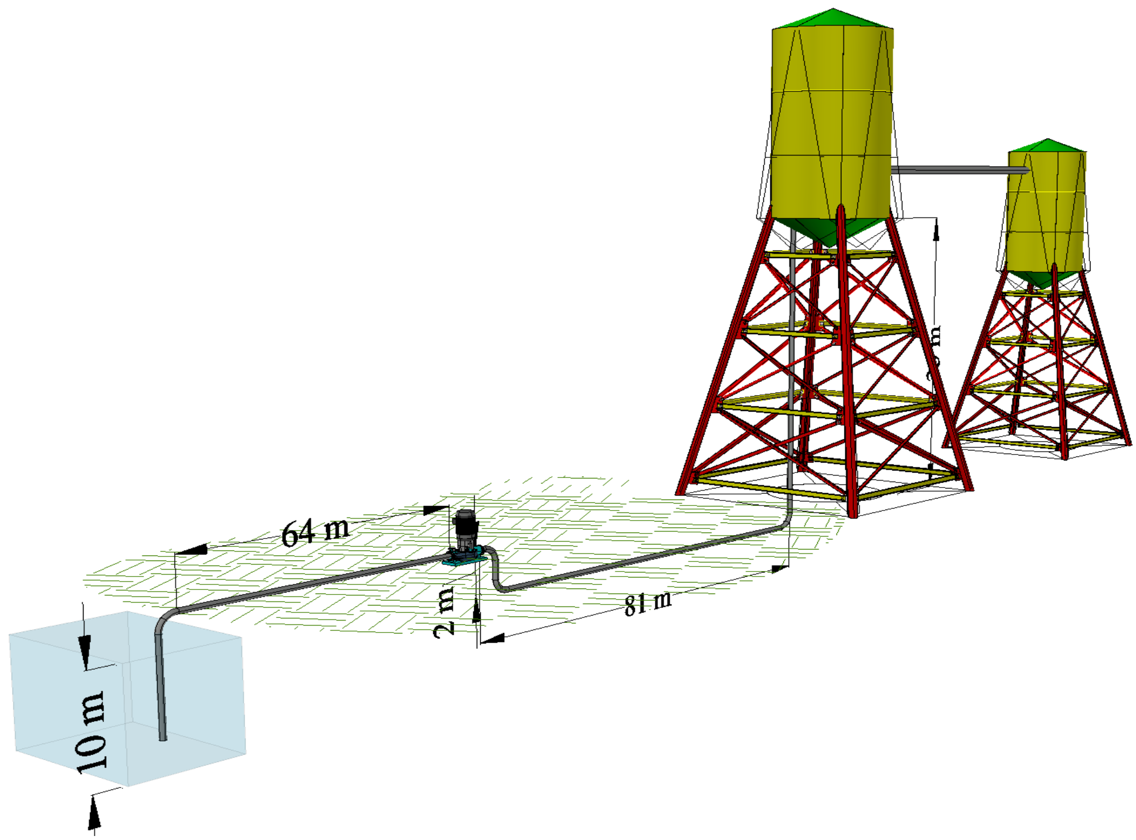

Figure 2: Side View of Pump System Design

Assumptions

For this project we are assuming that the Hazen Williams coefficient is 120, the power cost is $0.10 kW-hr. The water tower will be in a flat ground. The water label of the reservoir will be at a constant depth, the elbows of the pipes will be considered 90 degrees with (R/D = 2.0). More assumptions that are related to costs can be found in Appendices . In addition, we are assuming that the density of the water will be constant for the year.

METHODOLOGY

Location of the Pump Station

To determine the location of the pump station on the site, we considered the restrictions given. Only 75 meters of pipeline and one 90° elbow were allowed on the suction side of the pump. Since the reservoir was 10 meters-deep, we decided to use 9 meters of pipeline to go into the reservoir and the surface of the water of the reservoir is 1 m below ground surface. That left a total of 66 meters of pipeline to be located. Knowing this, we decided to place the pump station 65 meters away from the reservoir. On the delivery side, we were restricted to 120 meters of pipeline and three elbows. We knew that 35 meters of that length was needed to connect to the storage tank. The remaining 85 meters were used to connect the pump station and the 35-meter-long pipe.

Design Flow Rate

An average daily consumption rate was provided for every month of the year. Using this information, an average yearly consumption rate was determined. We had the option to design the pump system for this average value, however, we determined that doing so would result in a very high deficit for the months of high consumption; If we had designed for the average consumption rate, we would not have been able to meet the consumption demand during those high months. The design flow rate for the low demand months will be 145 L/s and for the high demand months will be 224 L/s. Storage tanks were designed to store the surplus water.

System Head Curve

Mr. Khanbilvardi required us to choose the pipe sizes, but restricted us to just three pipe diameters: 0.25 m, 0.30 m and 0.35 m. For each pipe diameter, we determined the total head loss due to friction using the Hazen Williams Equation. Minor losses remained constant because we had a fixed number of elbows and only one gate valve. Choosing the ground elevation as our datum, we calculated the static lift as 36 meters. This resulted in three different system head losses, H_p (See Appendix B for Calculations). Once we knew our systems, we started to combine pumps in parallel and in series until we covered at least one of our points of operation.

Pump Combinations

We came up with a total of three pump combinations but only 1 fit our design. We wanted our pump combinations to cover one or more of our operation points. We started by placing identical pumps in parallel to get to our design flowrate. Then we placed the parallel pumps in series with each other to get more head loss (See Appendix C for calculations). The initial and reoccurring cost was determined for each of the three options. We narrowed down our options to one combinations by looking at the cost, efficiency, operation point and flexibility. The final design will be chosen based on how well performs on all of the above.

Storage Tank

Our strategy for the storage tank was to design it based on our monthly surplus. From January to May we have a surplus equaling to 1,118,389.80 million gallons of water. This surplus will be needed to satisfy the consumption demand from June to September. We realized that this is a lot of water and that we will need to design more than one tank to hold it (See Appendix D for calculations). Our tank designs were based on the standard storage tanks available for construction.

DESIGN OPTIONS

Through the process of elimination, there were 2 viable options. If the flow rate is kept constant, at 145 L/s for the 8hour design and 224L/s for the 16hour design, the pipe, fittings and pumps could be variable to obtain the most energy efficient and cost-efficient option. The first option consists of pipes, connections and a valve of 0.35 m diameter size. The pipes will be connected to a pump station which has two pumps (both No. 4, 3250 RPM) in parallel, which are in series with another set of two pumps (both No. 4, 3250 RPM). The second design option will also use pipes, connections and a valve of 0.3 m diameter. The pump station will be set up with two pumps (No. 3, 4350 RPM) in parallel, which are in series with another set of the same two pumps in parallel.

Option 1: 0.35m pipes, connections, & valve, with the following pump configuration:

(P4||P4) -- (P4||P4) (3250 rpm)

Option 2: 0.3m pipes, connections, & valve, with the following pump configuration:

(P3) -- (P3||P3) (4350 rpm)

Pipe Selection

We will choose the pipe with a diameter of 0.35 m since it has the lowest system head in comparison to the other two pipes. In addition, the operating point for 8 hours of 0.35 pipe is 145 L/s with Head of 37.94m, for 16 hours 224 L/s with 40.44m head.

HYDRAULIC ANALYSIS AND CALCULATIONS

Option 1:

The 8 Hour design must pump water to the tank 8 hrs/day for the low demand months, the 16 hour design must pump water to the tank 16 hours a day for the high demand months. For this design, we are utilizing pump IV with 3250 rpm. The main idea of this system is to pump for all the values of the average daily consumption of each month starting from January to December. We found out that the highest value for the monthly average daily consumption is 250 L/s (0.250 m^3/s) which belong to the month of August. This value makes sense since August has the hottest days of the year which means people will be using water more frequently. We will be creating a pump system where that high demand value will be met with the lowest amount of head possible. Our pump setup for the high demand is composed of 4 pumps of the same type, but it will be connected 2 in series and 2 in parallel which gives double the head and double the flow rate. This configuration meets our system head curve standards with the value of 0.296 m^3/s with a head of 43.5 m. This high demand system will be paired up with a low demand system. The low demand system on the other hand, is configured so that the months that require less average daily consumption are fulfilled by a system that has less flow rate so that costs can decrease. The minimum flow that we must obtain from the system for low demand is 145 L/s (0.145 m^3/s). The way we can achieve this is by having 2 of the same pumps connected in series which gives us a value of approximately 0.173 m^3/s with a head of 38.5m, which will fulfill to about half the year of consumption values. The maximum flow that we must obtain from the system for high demand is 224 L/s (0.224 m^3/s). The way we can achieve this is by having 2 of the same pumps connected in series and 2 in parallel which gives us a value of approximately 0.296 m^3/s with a head of 43.5m, which will fulfill the high demand period. Figure in Appendix C shows each characteristic and system curves getting to our operating goal.

The following figure shows our configuration design which satisfied our high and low demand flow rates. For the high demand we need all four vertical pumps with a set-up of series and parallel with the same pump type, meanwhile the low demand only needs 2 of the same pumps in series. To change the mechanics of the system, we simply used 1 gate valve that prevents the water to go to the other two pumps when they are inactive. The following figure is a visual representation of our final choice.

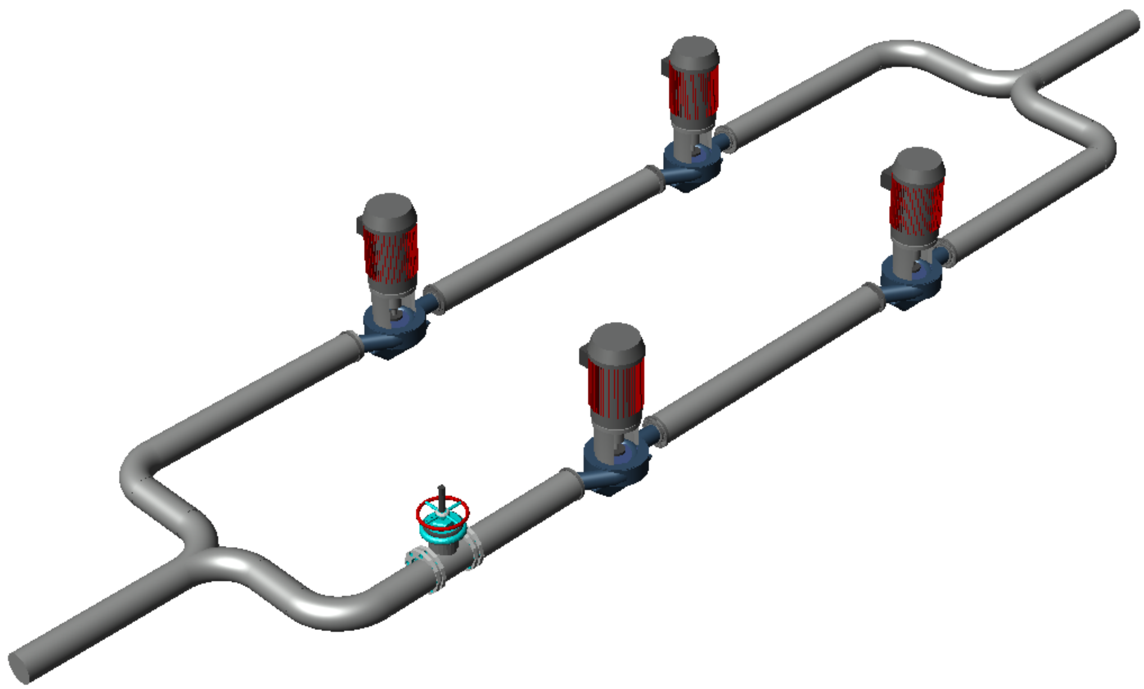

Figure 3: Chosen Pump Configuration

Efficiency for Option 1:

The operation point for the 0.35 m diameter piping system is Q_o=224 L/s, H_o=40.44 m. Using the pump characteristic curves available, the efficiency of each pump can be calculated as follows:

$$Q_o = 224 \text{ L/s} = 7.91 \text{ ft}^3\text{/s}$$

$$H_o = 40.44 \text{ m} = 132.67 \text{ ft}$$

Density of water(Ɣ) = 62.4 lb/ft^3

Power in (P_{in}) for Pump No. 4 running at 3250 rpm: P_{in} = 57 hp

P_{in} for system = 4*Pin = 4*57= 228 hp

Power out (P_{out}) = Q*Ho*Ɣ/550= 7.91*132.67*62.4/550= 119.06 hp

System efficiency = Po/Pin = (119.06/228)*100 = 52.21%

Efficiency for Option 2:

Q_o= 224 L/s = 7.91 ft^3/s

H_o=40.44 m = 132.67 ft

Density of water(Ɣ) = 62.4 lb/ft^3

Power in (P_{in}) for Pump No. 4 running at 4050 rpm: P_{in} = 138 hp

P_{in} for system = 4*Pin = 4*138= 552 hp

Power out (P_{out}) = Q*Ho*Ɣ/550= 7.91*132.67*62.4/550= 119.06 hp

System efficiency = Po/Pin = (119.06/552)*100 = 21%

COST ANALYSIS

Another factor to consider in the selection of the pipes and the pumps is the initial cost and the lifetime cost of the chosen system.

Cost of Design Option 1:

Using Pump IV 3250 in series and parallel we can obtain the following:

Initial cost = Pump Cost + Pipe Cost + Connection Cost + Valve Cost + Motor Cost

- Pump Cost = 4*($1000) = **$4,000**
- Pipe Cost (0.35 m Pipe) = (195m/10m)*$180+4 elbows* $35 + 1 gate valve*$120 = $3,770
- Motor Cost = 4 pumps*$134.50 = $537.98
- Initial cost = $4,000 + $3,770 + $537.98 = **$8,307.98**

Yearly Cost = [($0.09/kW-hr)*(Off Peak usage) + ($0.10/kW-hr)*(Peak/Partial Peak usage)]*350 days

- P_{in} = 228 hp = 170.020 kW and if we run 4 hours during off peak and 4 during peak usage and 8 hours during off peak and 8 during peak usage :
- Usage = (4hrs)*(170.020 kW) = 680.08kW-hr

- Usage = 8hrs*(170.020 kW)=1360.16kW-hr
- Yearly Cost =(($0.09/kW-hr)*(680.08 kW-hr) + ($0.10/kW-hr)*(680.08 kW-hr))*240days = $31,011.65
- Yearly Cost =(($0.09/kW-hr)*(1360.16 kW-hr) + ($0.10/kW-hr)*(1360.16 kW-hr))*110 = $28436.75
- Total : $28,436.75+ $31,011.65= $59,448.34

Cost for Option 2:

The same calculations where obtained for option 2 but the efficiency and cost did not meet our expectations.

In order to get the cost of the motor, we had to use our obtained horse power for each design and plug those values in the x variable in the formula shown in the following figure:

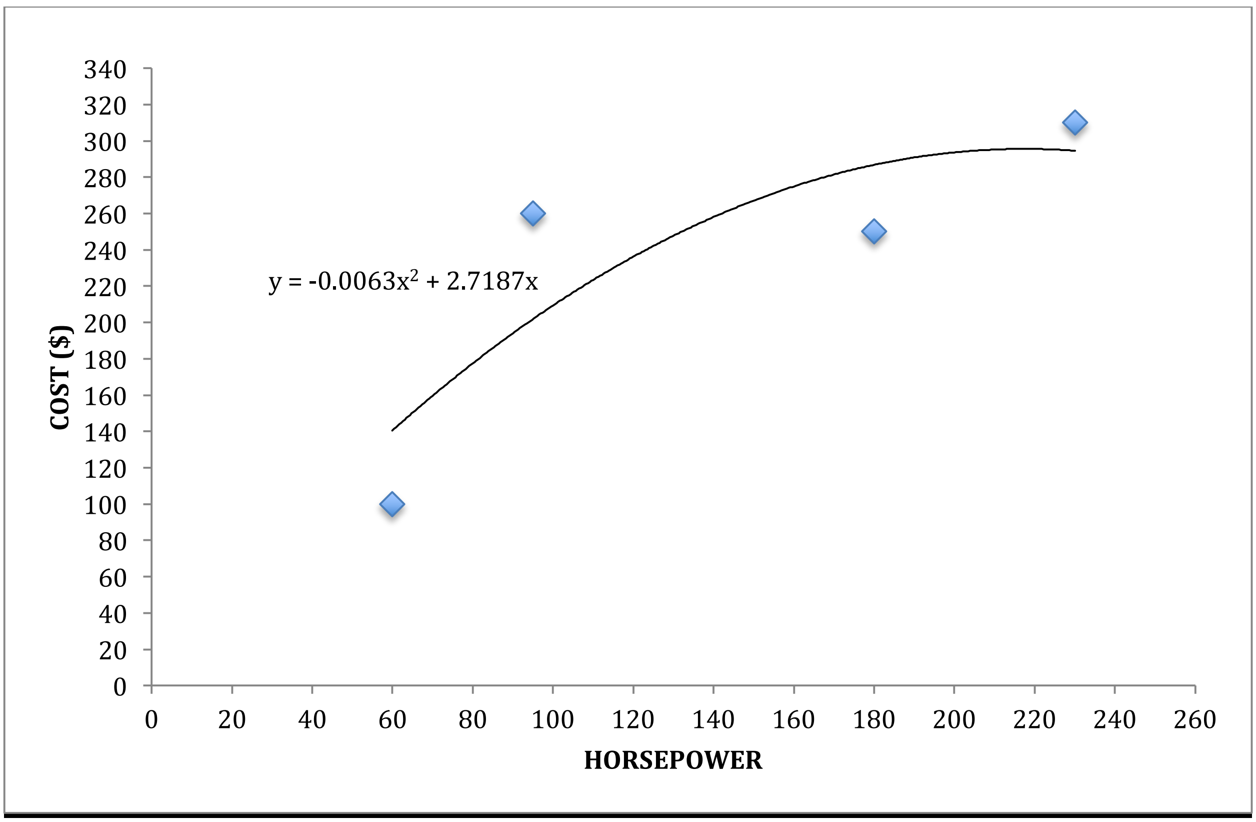

Figure 4: Motor Cost Curve

DISCUSSION OF RESULTS

Originally, we designed 3 different pump stations, two different pipe-networks and one storage tank combination. The overall deciding factors can be found in Appendix C. The two combinations containing Pump 3 at varying RPM were eliminated, because they resulted in a higher cost and very low efficiency when compared to the other combination. The deciding factor in this case turns out to be the initial installation cost, efficiency and the yearly recurring cost.

FINAL DESIGN SELECTION

Design Option 1 proves to be the best option we provide. This option is the most energy efficient, yielding an efficiency of 52.21%. The total cost of water delivery material is $8,307.98 and the yearly cost of operation is estimated as $59,448.34. This option also provides the freedom of allowing technicians to switch from 8hour to a 16hour, also to run or shut off more than one pump when needed. This is very useful when there is a change in water consumption, a pump malfunction or a change head during the course of the year. This design option includes pipes that are 0.35 meters in diameter. It also includes three Water Tanks of varying capacities. Our holding capacity must be greater than 1,118,398.80 million gallons, which is why we have chosen one 1-million-gallon fluted column tanks and one 125,000 gallon tank. Specific tank dimensions can be found in appendix D.

CONCLUSION

At JEineers PLLC, we strive to provide our clients with the highest quality of work. The board director has requested a pumping system with the optimum design in mind. We have provided a selection of pump stations and pipe networks that work within the given restrictions. We have provided an initial cost of $8,307.98 for the final design. This initial cost does not include the cost of the water tanks. We have designed our pumping system to operate for 8 hrs/day during low demand months and for 16 hrs/day for high demand months, during the off-peak hours (late night and midafternoon). The pumps will fill up the water tanks while consumption is very low, which will allow the tanks to hold enough water to satisfy the consumption during peak hours.

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Willner, T. (2017). “Fluted Column Steel Water Tank | Steel Water Storage Tank | Phoenix.” *Phoenix Tank*, Phoenix Tank, <http://phoenixtank.com/elevated-water-storage-productscomposite-elevated-water-tank/elevated-steel-water-tank/fluted-column-tanks/> (Dec. 14, 2018).

APPENDIX A: DESIGN FLOW RATE CALCULATIONS

Table 1: Average Daily Water Consumption, Surplus and Deficit for each month.

Last Year Daily Consumption			**Surplus and Deficit**			
Month	Demand	ADC(L)	Q(l/s)	Difference From ADC (L^3/s)	Surplus(m^3)	Q left behind (L^3/s)
January	Low	101	145	44	49	44
February	Low	110		35		79
March	Low	150		-5		74
April	Low	170		-25		49
May	Low	145		0		49
June	High	200	224	24	1	73
July	High	240		-16		57
August	High	250		-26		31
September	High	205		19		50
October	Low	160	145	-15	20	35
November	Low	145		0		35
December	Low	110		35		70

The following information was provided in the project description. The average yearly consumption rate was used to determine the design flow rate. We started with the average yearly consumption rate as the design flow rate. This allowed us to increase or decrease the value of the flow rate based on the surplus and deficit at the end of each month. We never wanted to have a negative flow rate at the end of the month because that meant that we did not have enough water to supply our demand.

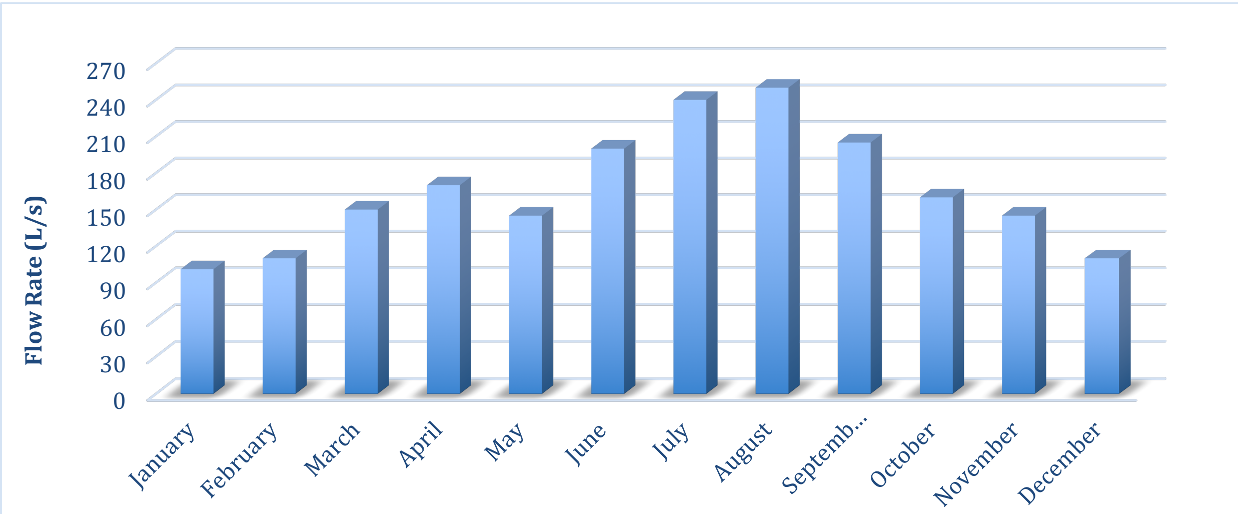

Figure 5: Last Year Consumption

APPENDIX B: SYSTEM HEAD CURVES

The following information was provided in the project description;

Pipe Diameter (m)	0.25 ($)	0.30 ($)	0.35 ($)
Pipe (10 m long)	120	150	180
Elbow	15	25	35
Gate Valve	60	90	120
Check Valve	80	105	130

Table 2: Cost of pipes, elbows and valves for different pipe diameters

We came up with three different system head curves using a static lift of 36 meters. The major and minor head losses depended on the diameter of each chosen pipe. We calculated the major head losses using the Hazen Williams Equation,

$$V = 0.849\, C_{HW} H_R^{0.63} S^{0.54}$$

The following secondary equations were also used,

$$S = \frac{h_f}{L}$$

$$V = \frac{Q}{A}$$

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

The minor losses were calculated using the following equation,

$$h_l = \frac{V^2}{2g} \sum K$$

Where the K values were obtained for the gate valve, the entrance to the water tower, the exit from the reservoir, the four 90° elbows and the gate valve.

System Head Curve #1:

$$D_1 = 0.25\ m$$

a. Major Losses

$$h_{f_1} = L\left[\frac{4^{1.63} * Q}{0.849 * \pi * C_{HW} * D_1{}^{2.63}}\right]^{\frac{1}{0.54}} \quad \text{or} \quad \frac{10.7LQ^{1.85}}{D^{4.87}C_{HW}^{1.85}}$$

b. Minor Losses

$$h_{l_1} = \sum K * \left[\frac{Q^2}{2 * g * \left(\frac{\pi}{4}\right)^2 * D_1{}^4}\right]$$

c. Total Head for System:

$$H_p = S.L. + h_{f_1} + h_{l_1}$$

System Head Curve #2:

$$D_2 = 0.30\ m$$

d. Major Losses

$$h_{f_2} = L\left[\frac{4^{1.63} * Q}{0.849 * \pi * C_{HW} * D_2{}^{2.63}}\right]^{\frac{1}{0.54}} \quad \text{or} \quad \frac{10.7LQ^{1.85}}{D^{4.87}C_{HW}^{1.85}}$$

e. Minor Losses

$$h_{l_2} = \sum K * \left[\frac{Q^2}{2 * g * \left(\frac{\pi}{4}\right)^2 * D_2{}^4}\right]$$

f. Total Head for System:

$$H_p = S.L. + h_{f_2} + h_{l_2}$$

System Head Curve #3:

$$D_3 = 0.35\ m$$

g. Major Losses

$$h_{f_3} = L\left[\frac{4^{1.63} * Q}{0.849 * \pi * C_{HW} * {D_3}^{2.63}}\right]^{\frac{1}{0.54}} \quad \text{or} \quad \frac{10.7 L Q^{1.85}}{D^{4.87} C_{HW}^{1.85}}$$

h. Minor Losses

$$h_{l_3} = \sum \quad K * \left[\frac{Q^2}{2 * g * \left(\frac{\pi}{4}\right)^2 * {D_3}^4}\right]$$

i. Total Head for System:

$$H_p = S.L. + h_{f_2} + \ h_{l_2}$$

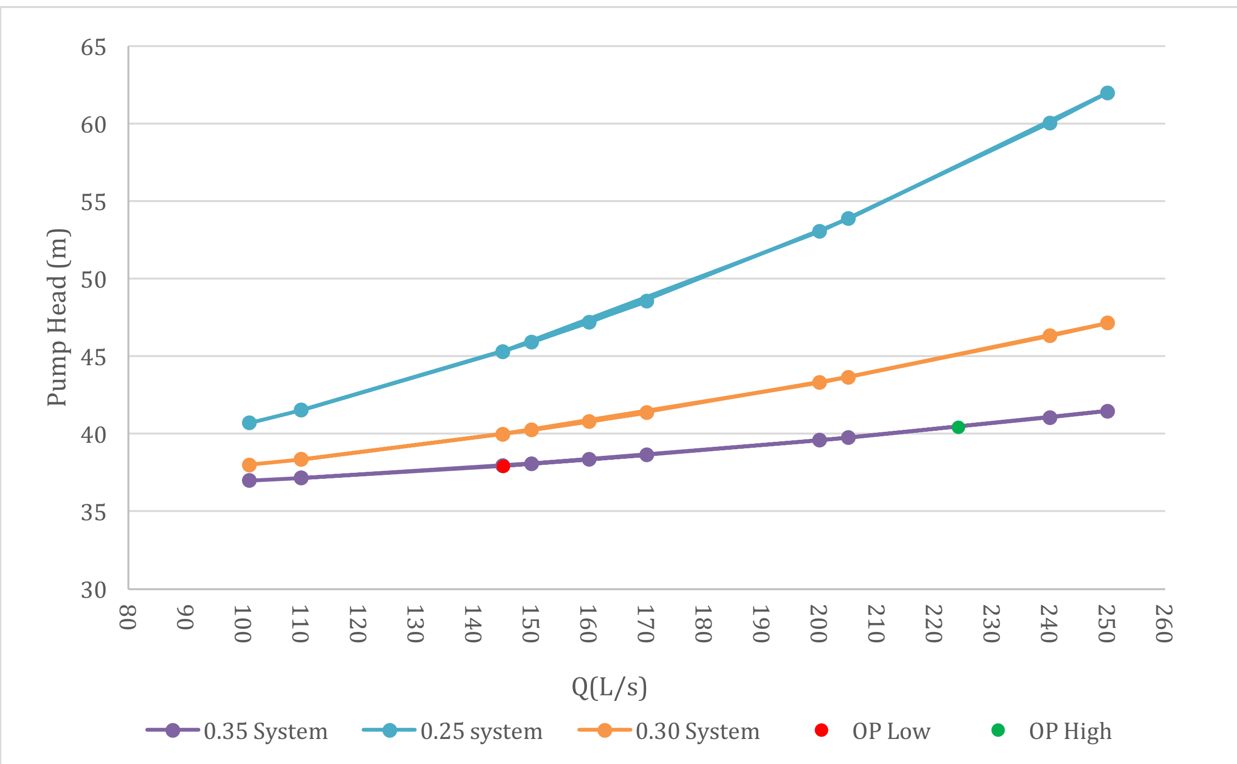

Figure 6: Operating Point and System Curves for Varying Pipe Diameters

In order to obtain our system head curves from the three selections of pipes, we must first calculate our head losses. Head losses are subdivided into major and minor losses. Since we were given a Hazen-William coefficient with the value of 120, we have to use the following equation:

$$hf = KQ^{m} = 10.7LQ^{1.85}/D^{4.87}CHW^{1.85}$$

The above equation represents head loss due to friction (major). L is the total length of the pipe system in meters, D is the diameter used from each pipe, C_{HW} is the Hazen-Williams coefficient and Q is the flow rate which will depend on the average daily consumption flow rate for each month in one whole year.

On the other hand, minor losses can be determined by using:

$$hminor = KV^2/2g = KQ^2/2gA^2$$

The minor loss equation has a few components that can be easily gathered. K is a constant based on the system component that we are using for this project, we assumed that gate valve was fully open and the check valve was swing type(fully open), Q is the flow rate that can be found from the given consumption data, g is acceleration due to gravity in SI units and A is the cross sectional area of the pipe used. The following table identifies important data in order to proceed to our calculations.

Table 3: Important Values for System Curve Computations

System Components	# of items	K value
Entrance	1	0.5
Gate Valve		0.15
Check Valve		2.5
Exit		1
Elbows	4	4(0.19)
	Total K:	4.19

To properly complete our System Curve, we must follow the Total Energy equation which states that:

$$(Z + P/\gamma + V^2/2g)_1 + h_{pump} = (Z + P/\gamma + V^2/2g)_2 + h_{Loss}$$

If we solve it, we can see that we are only left with:

$$h_{pump} = (Z_2 - Z_1) + h_{Loss}$$

For the head pump, we must add total energy and head losses. Total energy(Z2-Z2=36 m=hs). Once we have followed with the correct procedure, we came up with the following values for each pipe diameter.

Table 4: Derivation of Terms for the System Curves

Pipe Diameter (m)	Area (m^2)	K due to friction	hf	Minor Loss	hminor	hs
0.25	0.049085938	254.0769349	254.07Q^1.8	102.816700	102.81Q^2	36
0.3	0.07068375	104.5568699	104.55Q^1.8	49.5836710	49.58Q^2	
0.35	0.096208438	49.35392626	49.35Q^1.85	26.7640306	26.76Q^2	

Pipe	System Head Equation
0.25	36+102.81Q^2+254.07Q^1.85
0.3	36+49.58Q^2+104.55Q^1.85
0.35	36+26.76Q^2+49.35Q^1.85

Table 5: Equations needed to graph System Curves for each Pipe

APPENDIX C: PUMP COMBINATIONS

The following information was provided to us in the project description,

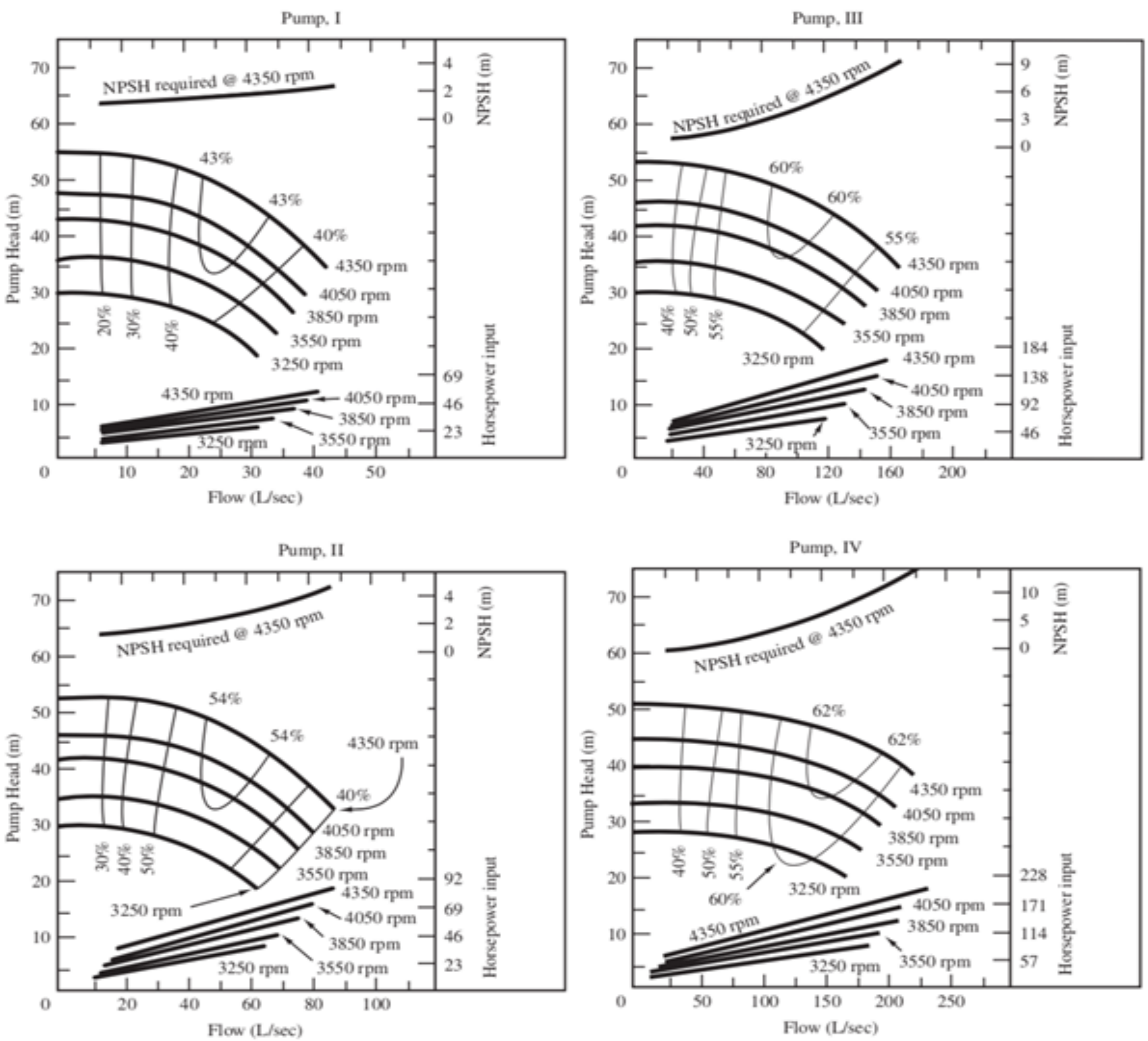

Figure 7: Characteristic Curves for four different pump models

Using our best approximation, we recreated these curves in excel, which allowed us to combine the pumps for the purpose of this project.

First Pump Combination:

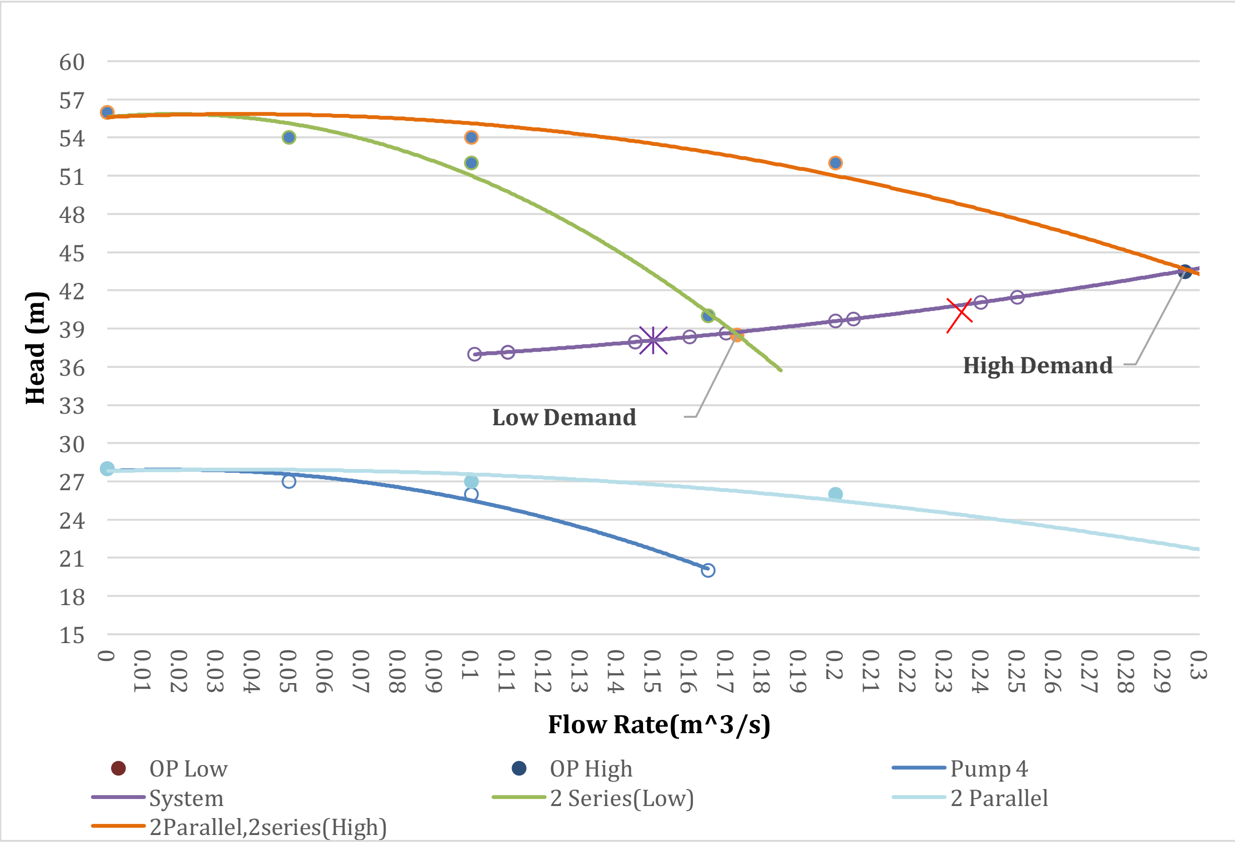

Figure 8: Operating Points vs. Pump 4 running at 3250 RPM.

Pump IV (3250)		Pump 4 in Series		Pump 4 in Parallel		Pump 4 in (2 series) and 2 parallel	
Q (m^3/s)	Pump Head(m)	Q (m^3/s)	Head (m)	Q (m^3/s)	Head (m)	Q (m^3/s)	Head (m)
0	28	0	56	0	28	0	56
0.05	27	0.05	54	0.1	27	0.1	54
0.1	26	0.1	52	0.2	26	0.2	52
0.165	20	0.165	40	0.33	20	0.33	40

Table 6: First Pump Combination Points

Pump Used	Demand	Satisfied Flow Rate (m^3/s)	Head (m)	Configuration
IV	High (16hr)	0.296	43.5	2 Series, 2 Parallel
	Low (8hr)	0.173	38.5	2 Series

Table 7: Data gathered for the 16 hr and 8hr System

Second Pump Combination:

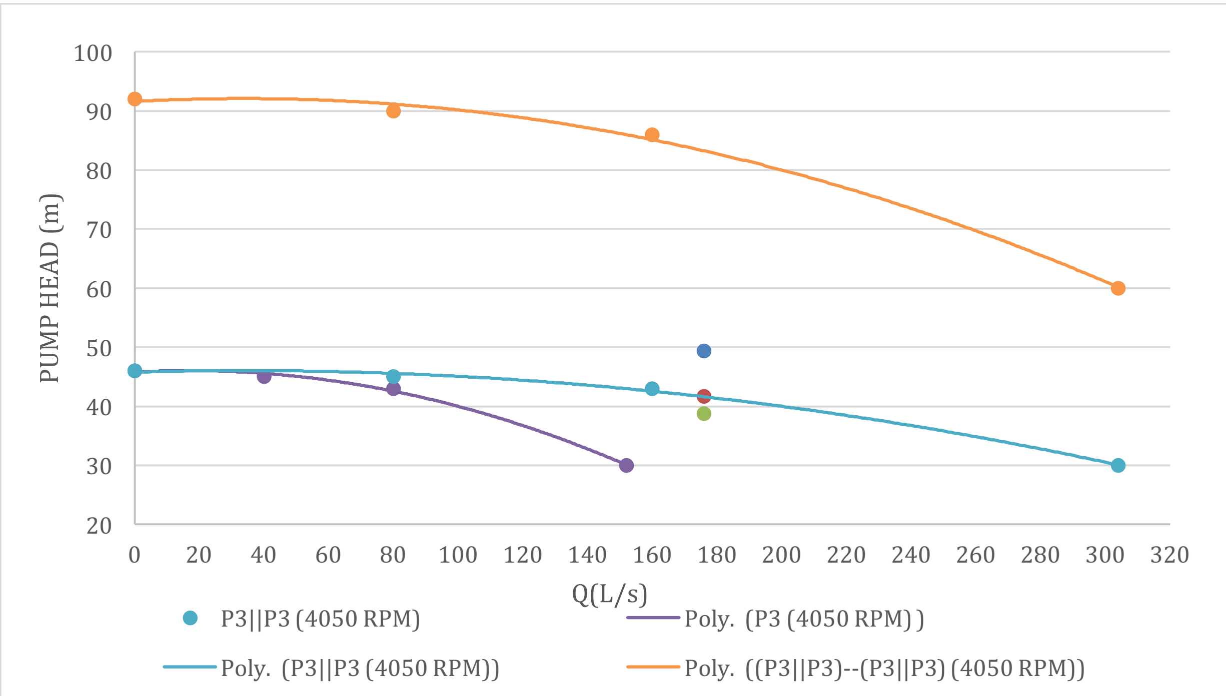

Table 8: Operating Points vs Pump 3 at 4050 RPM

P3 (4050 RPM)		**P3‖P3 (4050 RPM)**		**(P3‖P3)--(P3‖P3) (4050 RPM)**	
Q	H	Q	H	Q	H
0	46	0	46	0	92
40	45	80	45	80	90
80	43	160	43	160	86
152	30	304	30	304	60

Table 9: Second Pump Combination points

Third Pump Combination:

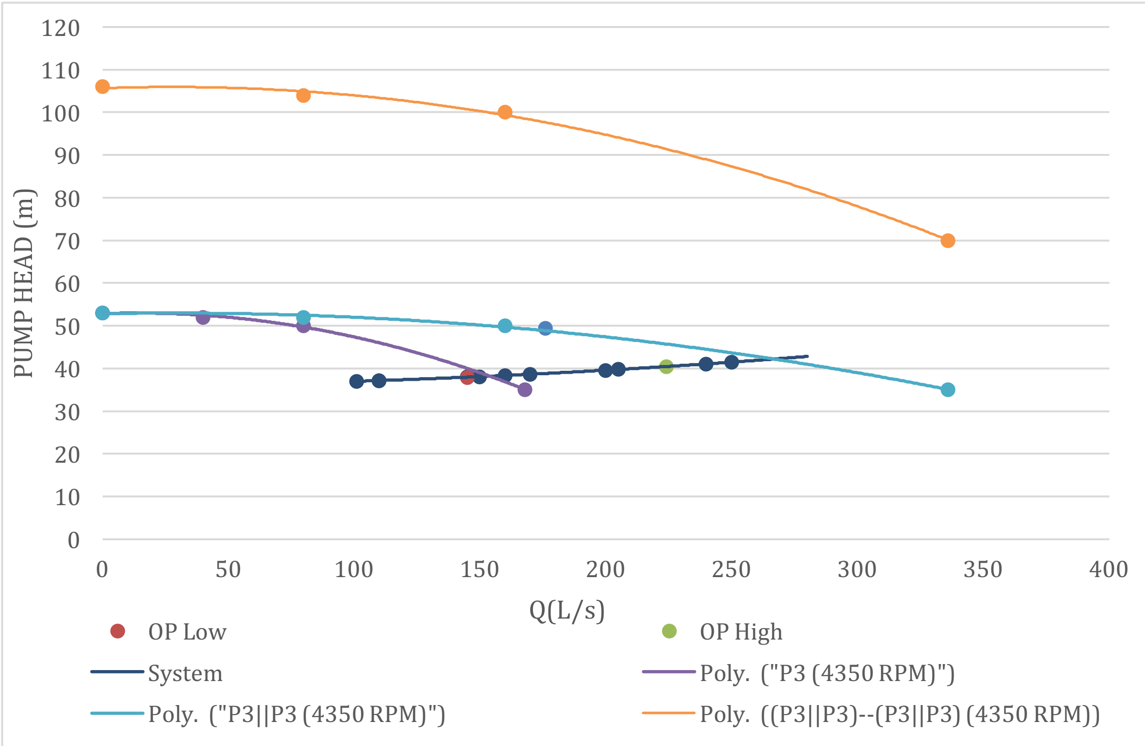

Figure 9: Operating Point vs. Pump 3 at 4350 RPM

P3 (4350 RPM)		**P3||P3 (4350 RPM)**		**(P3||P3)--(P3||P3) (4350 RPM)**	
Q	H	Q	H	Q	H
0	53	0	53	0	106
40	52	80	52	80	104
80	50	160	50	160	100
168	35	336	35	336	70

Table 10: Third Pump Combination Points

COST & EFFICIENCY ANALYSIS			
SET UP	**INITIAL COST**	**YEARLY COST**	**EFFICIENCY**
(P4||P4)--(P4||P4) (3250 RPM)	$8,307.98	$59,448.34	52.21%
(P3||P3)--(P3||P3) (4050 RPM)	$8990.80	74,645.65	21%
(P3)--(P3||P3) (4350 RPM)	$7780.90	62,573.76	23%

Table 11: Initial Cost, yearly cost and the efficiency.

APPENDIX D: STORAGE TANK CALCULATIONS

The storage tank was designed to hold the surplus water from January to May, which was the highest surplus for the whole year. The average surplus flow rate at the end of May was equal to 49 L/s. We assumed that the pump station would be running for only 8 hrs/day. In those 8 hrs, the pump station needed to provide enough water to meet the consumption demand. Using the surplus flow rate, we calculated the average volume of water needing storage in a given day,

$$Q_{surplus} = 49\frac{L}{s} = 4{,}233\ x10^{6}\,\frac{L}{day}$$

$$Volume_{w} = 4{,}233x10^{6}\ L = 1{,}118{,}398.80\ gallons$$

Based on the 1,118,398.8 million gallons of water needing storage and the storage tanks available on the market, we concluded that one large multi-leg tanks with a water capacity of 1 million gallons and one small multi-leg tank with a 125,000-gallon water capacity, would satisfy our storage needs. The tanks will be placed in series with each other and we are neglecting the length of the pipes connecting the three. The typical size for the 1million gallon tank is 75 feet in diameter and the small tank is 30 feet in diameter. All tanks have a cylindrical shape. The total cost for these types of tanks could not be found in any of our online or catalog searches. Since they are very large, the companies ask for the customer to obtain a quote from the builder, and we are still waiting for quotes to be presented. However, we are certain that these tanks are available.