Design of Hydraulic System for Nicaraguan School Building

Fluid Mechanics Project
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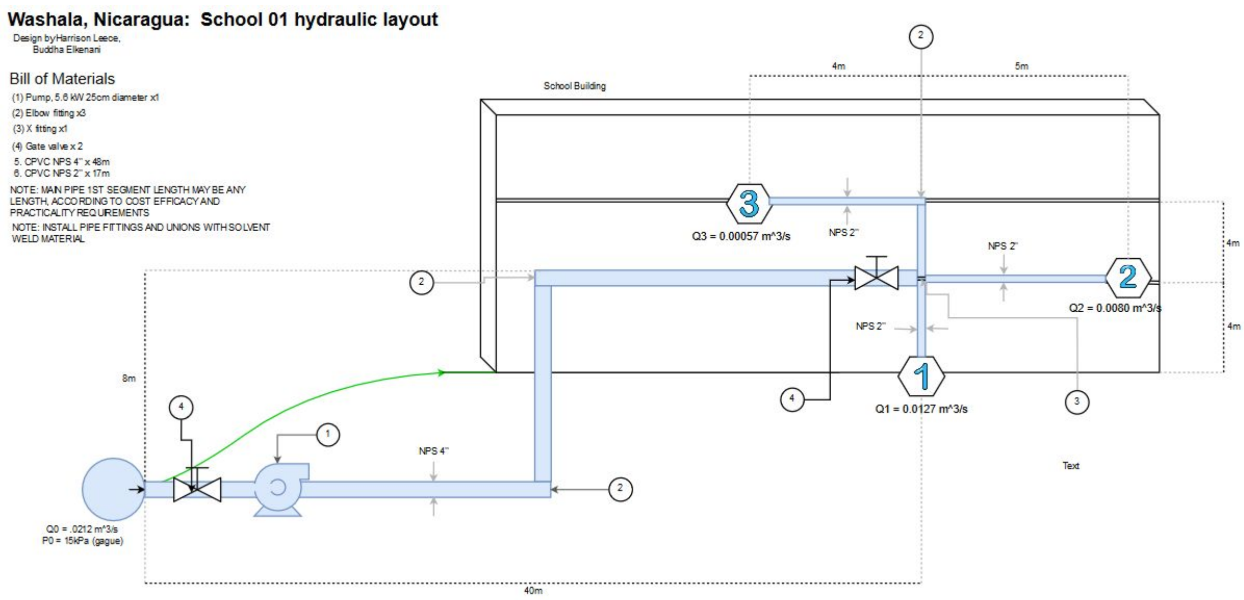
Problem Overview

Waslala Nicaragua has been tremendously impacted by the effects of the Nicaraguan revolution over the previous years. While the city has running power and water lines, much of the infrastructure needs upgrades or, the capacity to support a growing population. To support the ongoing wellbeing of the community, it is necessary to build a school building able to be autonomously supported by the people of Nicaragua. Because of this, it is necessary to build an energy efficient, cheap and reliable system at the potential cost of large factors of safety and feature richness which is expected from modern first world homes. Additionally, it is absolutely the most important thing that the water used is free from contamination and is never a health or environmental safety risk. The requirements determined by the architecture team indicates that a flow of water is required on all 3 floors of the school building, and that the location of the school building will be 30 meters from the school building, across the ground, and 4 meters below the first floor of the school building. The potable water line which will be tapped operates at 15kPa and the .0212 meters cubed per second is the expected volumetric flow rate into the intake pipe.

Design Overview



This plan requires the use of two (manually operated) gate valves for installation, maintenance and emergency shut of purposes. If a pump is necessary it will be located near the source, to keep emissions and noise away from the school building. Pipe diameters were selected based on a balance of cost and energy efficiency of the pump, as well as matching common sizes for easy maintainability. The geometry of the piping network minimizes the length of piping necessary to minimize cost and energy losses due to friction, while still allowing flow analysis at all outlets.

The equations used to describe the flow of the water at any outlet in this network can be described generally using the ‘energy equation’ which essentially a bernoulli's equation which accounts for energy loss.

$$0 = \frac{P_0}{\gamma} + \frac{V_o^2}{2g} + H_p - \frac{V_i^2}{2g} - z_i - f\frac{l}{D}\frac{V_i^2}{2g} - \Sigma k\frac{V_i^2}{2g}$$

Equation 1: Generalized energy equation for any outlet i, when all outlets diverge from mainline close to each other. P_0 and V_0 are known

$$0 = -\frac{Q_0}{A_1} + |v_1| + |v_2| + |v_3|$$

Equation 2: Conservation of mass equation

For three outlets there are three energy equations required to describe the velocity at any point, and a conservation of mass equation as a compatibility equation to also calculate the head of the pump required to achieve the flow rate. From these four equations with four unknowns, a numerical analysis package was used to find the roots of the energy equation and conservation of mass equation, and return flow rates at each outlet and the required pump head to achieve those flows.

Friction factor (f) was computed using Colebrooks' formula, using a while loop to find friction factor for a given roughness, diameter and reynolds number.

In the effort to analyze the designed system, a computer program which was able to rapidly analyze the performance of the piping network was necessary. To this end, code was produced to solve the energy equation for the flow velocity at every outlet and the required pump head to achieve that flow rate using 3 energy equations and a conservation of mass equation. The program utilized python's scipy package and the fsolve() function to numerically find the roots of the nonlinear system. Because the flow velocity is a function of the flow velocity, it was necessary to recompute friction factors after the flow velocity was solved, by finding the new reynolds number and using the

Colebrook formula to numerically find the friction factor. The new friction factor was used to find a new velocity, with a logic control gate to determine when the change in velocity was small enough to consider the solution to fsolve() as the physically correct solution to the system of energy equation. Bellow is the flow control diagram of the code.

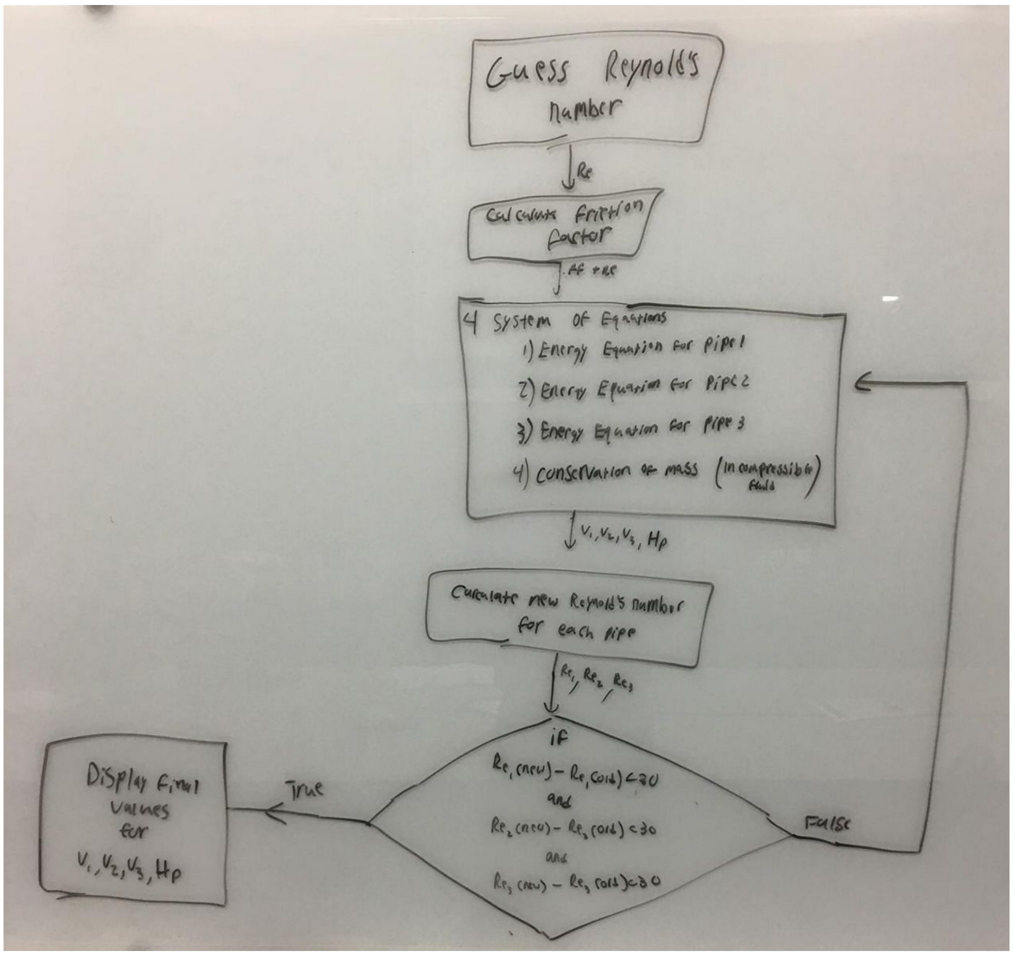


Figure 2: Flow control diagram for the python code

For this design, a pump has been determined to be necessary due to the low pressure supply condition and relatively high elevation requirements. Even without frictional losses due to the pipe or fittings factored into the energy equation, the elevation the water can reach from the just the pressure and velocity of the supply line is approximately 1.7 meters, where as a 12 meter displacement is required to reach the highest outlet as stipulated in the architecture requirements. The calculation for this idealize case can be seen in **Figure 1** below.

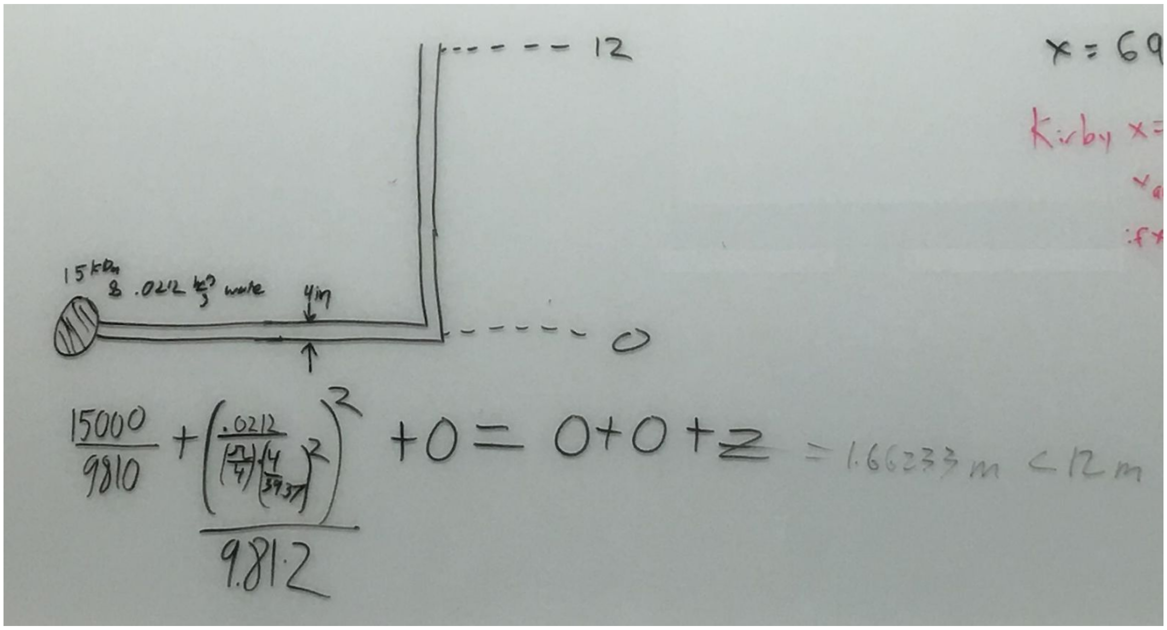


Figure 1: Bernoulli's equation applied to the system in an ideal (no energy loss) condition

The material chosen for this piping system was CPVC, due to its high toughness (resistance to hydraulic hammer), ease of install\maintenance (solvent welding rated), acceptable strength, low friction factor, low susceptibility to corrosion, low cost and relatively high operating temperature. Overall, CPVC is a safe, trusted, low cost and reliable material which can be trusted to perform well for this task.

<u>Results</u>

Utilizing this python script, volumetric flow rate with NPS 4'' main line and NPS 2'' outlet lines are Q1 = 0.0127 meters^3/s, Q2 = 0.0080 meters^3/s, Q3 = 0.00057 meters^3/s, with a required pump head requirement of 12.6 meters to achieve this flow rate. Modulation of this flow rate can be controlled by the installation of valves. Decreasing the flow rate would increase the flow at 2 and 3, allowing more precise control of water distribution throughout the building.

Based on this required head, a pump can be chosen in accordance with the requirements, along with a review of the reliability and factor of safety needed. From the pump chart in **Figure 3**, a pump of 10’’(25 cm) diameter, and 7.5 HP (5.6 kW) was determined to be necessary for this design.

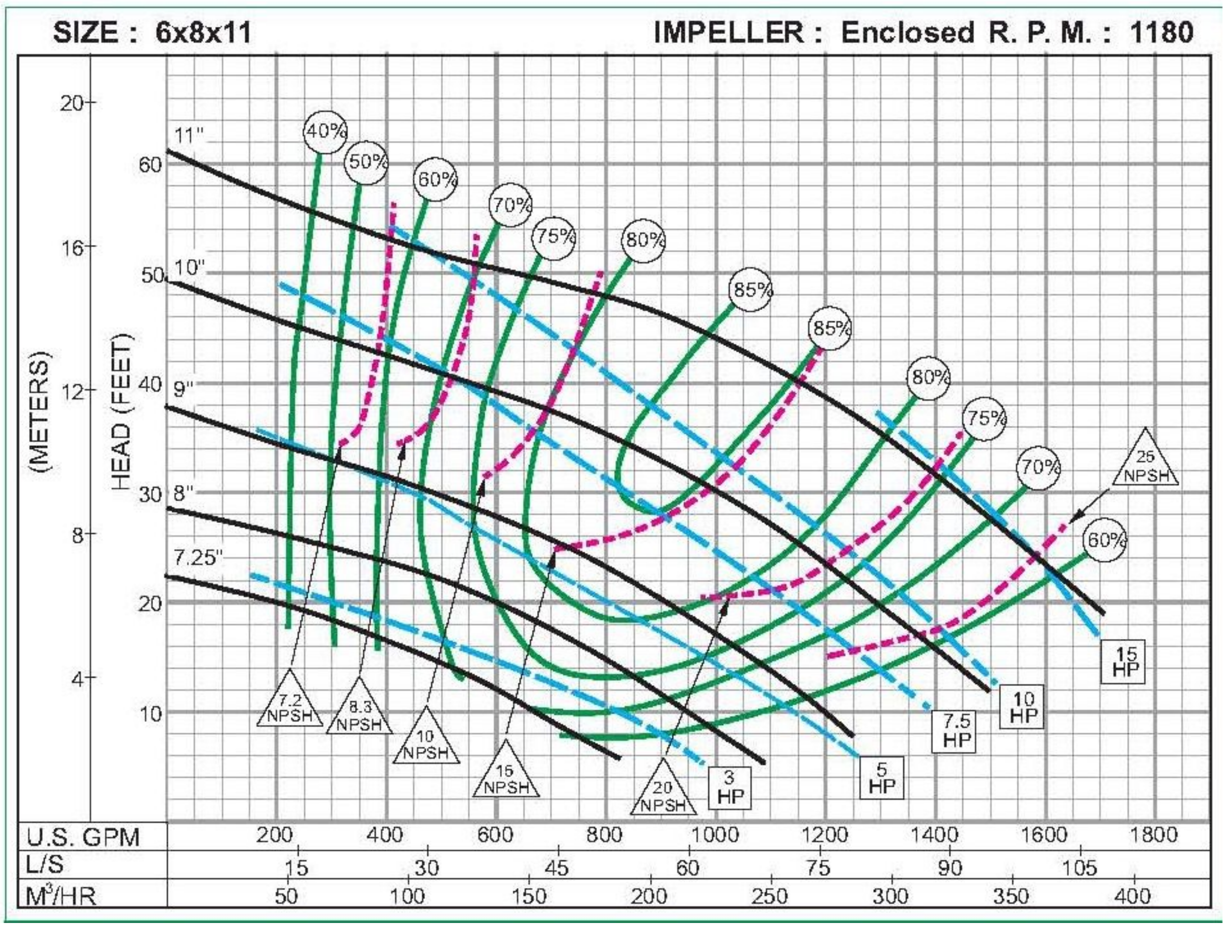


Figure 3: Pump selection chart [1]

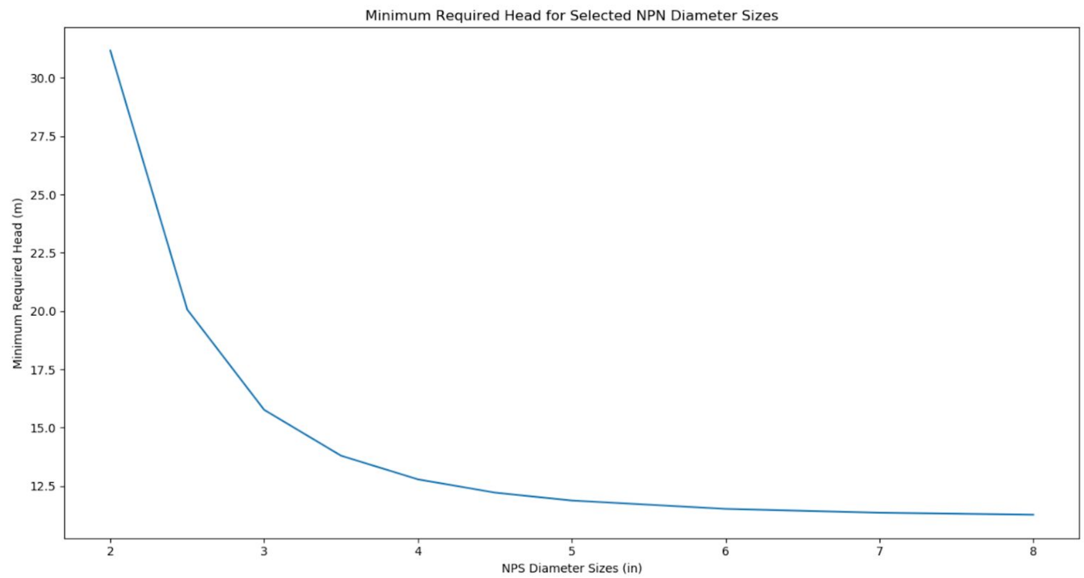


Figure 4: Fluid-network python script generated plot, which describes minimum required head for specific main line diameter sizes

Also produced in this code was a plot of required head versus NPS diameter. **Figure 4** shows with increased diameter, minimum required head decreases hyperbolically. This is because with larger diameter, there is a larger area and therefore less friction losses, which matches the equation for friction factor shown below.

$$C_d = f\frac{l}{D}\frac{V^2}{2g}$$

Equation 3: Energy loss of a pipe of diameter (D), length (l), velocity (V), friction factor (f), and gravity constant (g). [2]

The ideal pipe to buy would therefore be the one with the largest diameter in terms of just energy losses.

Corzan® CPVC (Duct/Pipe)						
Part No.	Size	(O.D.)	Wall	Std. Length	List Price per ft.	List Price per ft.
	Extruded				10'	20'
1833-PP-02	2"	2.375"	0.154"	10 ft. or 20 ft.	$10.98	$10.43
1833-PP-03	3"	3.500"	0.216"	10 ft. or 20 ft.	$22.65	$21.54
1833-PP-04	4"	4.500"	0.237"	10 ft. or 20 ft.	$36.58	$32.29
1833-PP-06	6"	6.625"	0.187"	10 ft. or 20 ft.	$42.85	$40.72
1833-PP-08	8"	8.625"	0.187"	10 ft. or 20 ft.	$72.80	$69.19
1833-PP-10	10"	10.750"	0.187"	10 ft. or 20 ft.	$109.39	$103.98
1833-PP-12	12"	12.750"	0.187"	10 ft. or 20 ft.	$130.17	$123.63
1833-PP-14	14"	14.000"	0.187"	10 ft. or 20 ft.	$160.16	$152.19
1833-PP-16	16"	16.000"	0.187"	10 ft. or 20 ft.	$183.21	$174.06
1833-PP-18	18"	18.000"	0.187"	10 ft. or 20 ft.	$221.41	$210.35
1833-PP-20	20"	20.000"	0.219"	10 ft. or 20 ft.	$267.12	$253.78
1833-PP-24	24"	24.000"	0.250"	10 ft. or 20 ft.	$366.13	$347.81
	Rolled					
1834-PP-22	22"	22.000"	0.187"	4 ft. w/Coupling	Contact Factory	Contact Factory
1834-PP-26	26"	26.000"	0.187"	4 ft. w/Coupling	Contact Factory	Contact Factory
1834-PP-28	28"	28.000"	0.187"	4 ft. w/Coupling	Contact Factory	Contact Factory
1834-PP-30	30"	30.000"	0.187"	4 ft. w/Coupling	Contact Factory	Contact Factory
CPVC duct diameters thru 60" all available. Contact factory for details.						

Figure 5: Cost of CPVC pipe in NPS sizes [3]

However, the cost of the pipe increases linearly per inch increase of diameter of roughly $11. Since minimum head decreases asymptotically with increasing diameter, it would not be efficient to buy the pipe with the largest diameter, because the percent difference in price far outweighs the percent difference in minimum head required. An efficient diameter to choose is 4 inches, since after 4 inches the the head minimum requirement does not change drastically, since the rate of change of the graph diminishes significantly. A 4 inch diameter allows for a good balance between cost and performance.

<u>Conclusion</u>

In this project, analysis of design requirements and pipe network optimization was performed in order to create a theoretically sound piping network for a nicaraguan school. To minimize costs, materials and a pump were selected to meet minimum reliability and performance standards, as well as maintain health and safety of all occupants of the building. It is possible for further optimization of the system to be performed with alternative pipe networks, but more advanced analysis would be required to determine the physically accurate operation of more complex plumping networks.

Citations:

[1] "Process Design." *Process Design*, 2015, 15926.org/topics/process-design/index.htm.

[2] Gerhart, Philip M., et al. *Munson, Young, and Okiishis Fundamentals of Fluid Mechanics*. Wiley, 2016.

[3] "CORZAN® CPVC Duct Pipe." *Schedule 40/80 PVC Pipe Dimensions & Sizes | Pipe & Fitting Specifications*, www.harrisonplastic.com/aboutcpvc.html.