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CIVE330
Term Project - Cabin Water System Design Proposal
Due 03/22/24

Abstract

This report outlines the design and engineering considerations for equipping an existing cabin, lacking plumbing infrastructure, with an efficient water supply system. The design process adheres to specific guidelines, ensuring the system's efficiency and reliability. Key aspects of the design process included analyzing initial conditions, segmenting the design approach, utilizing detailed calculations and design methodologies to calculate head losses, velocities and pressures throughout the pipe network, creating a schematic drawing to analyze relativity of key aspects of the design, determining an optimal volume and elevation for a tank reservoir to hold water, selecting a pump based on these required specifications and estimating the quantities through a bill of materials for the overall project.

Utilizing thorough calculations and design methodologies, the report establishes a comprehensive and well planned strategy to meet the cabin's water supply needs. This multifaceted report lays a foundation for further project advancement, as this report is a preliminary step needed in the engineering design process, offering key insights for effective system implementation. In summary, this report provides a detailed blueprint for implementing a dependable water supply system for the cabin, offering crucial recommendations for project success.

1. Introduction

1.1. Goals

The goal for this project is to design the water supply system for a cabin we have inherited lacking plumbing infrastructure. The cabin has two stories, each floor at a height of 10 feet tall. Important goals for this project are ensuring that basic water needs for a comfortable living are met. The primary applications requiring water include a faucet, shower, water heater and washer. It was crucial that each water consumption unit must operate independent of each other and concurrently without majorly affecting each other. Moreover, we had to ensure that regardless of tank location, enough water pressure and flow rate is supplied to each unit in the cabin.

1.2. Objectives

Our objectives for this project are to (1) calculate the total head losses in each pipe to ensure that sufficient water pressure and flow rate is provided from the lake to the tank to the appliances, (2) determine the velocity for each pipe using an assumed diameter and a given flow rate, (3) find a pump that sufficiently transports water from the lake to the tank, based on required total head and flow rate which can provide enough water to the cabin and (4) comprehensively assess the quantities of each material and provide a cost estimate.

1.3. Requirements

The project requires that (1) the pump fills the tank up in a couple hours, (2) the system must effectively overcome friction and concentrated head losses, (3) the volume of tank must be sufficient to sustain cabin operations for a minimum of two days, (4) the floater mechanism in the tank activates when the tank is at 10% capacity, replenishing the tank within two hours and (5) to mitigate potential frost related issues, the pipe systems supplying water must be strategically placed below the frost level while still maintaining operational efficiency (2 feet).

1.4. Assumptions

Assumptions for this project are (1) the pipe material is PVC due to its durability and cost effectiveness (e=0.000005 ft), (2) the fluctuations in lake elevation due to rainfall can be neglected due to pump location being two feet below ground level, (3) the junction, elbow or bend pieces head loss and price are being neglected as it may be minimal and this is a preliminary report, (4) it is assumed that for proper water pressure, the water tank's height is approximately 2-3 meters above the shower head elevation to ensure proper flow and pressure distribution throughout the house and (5) all diameters for pipes were assumed and then checked at the end of the total calculation to ensure the velocity was reasonable.

2. Design Description

Designing a water system for an existing cabin entails adherence to specific existing guidelines within the engineering design process. The topographical diagram provided (Figure 2) showed the lake at an elevation of 626 feet and the house at an elevation of 644 feet. Thus, the cabin is on a hill 450 feet away from the lake reservoir at an elevation of 18 ft from the bottom of the hill. The cabin is a two story building with 10 feet floors and the shower head is at an elevation of 6.5 feet from the second floor.

In our design approach, we wanted to calculate the head loss throughout the entire system and we broke it up into three segments: (1) junction point to each appliance, where there are four appliances, (2) tank to a junction point and (3) pump to tank. The junction point to appliances was calculated first as the average demands for each appliance was available (see references). The tank to pump was calculated last, as finding a suitable pump was our objective.

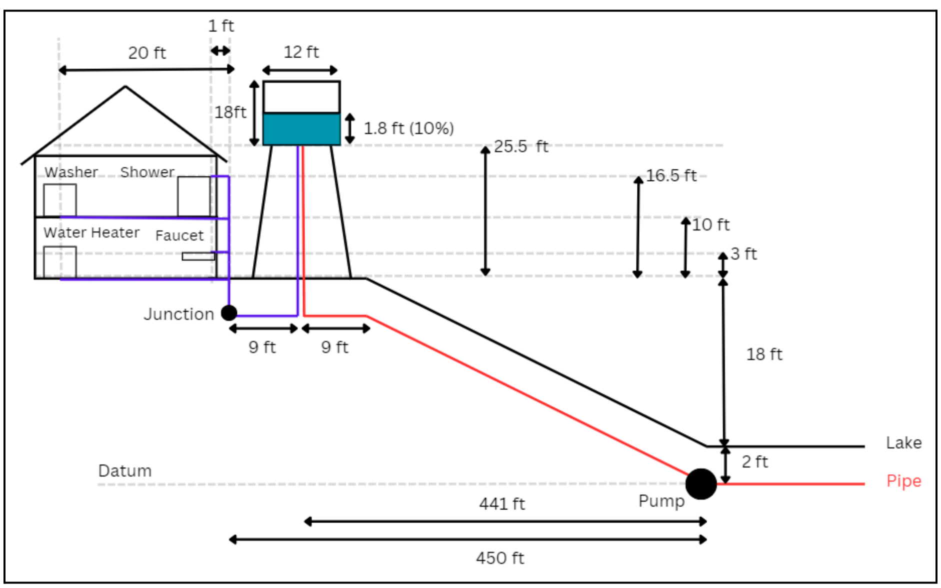

Figure 1. Schematics Diagram of Water System

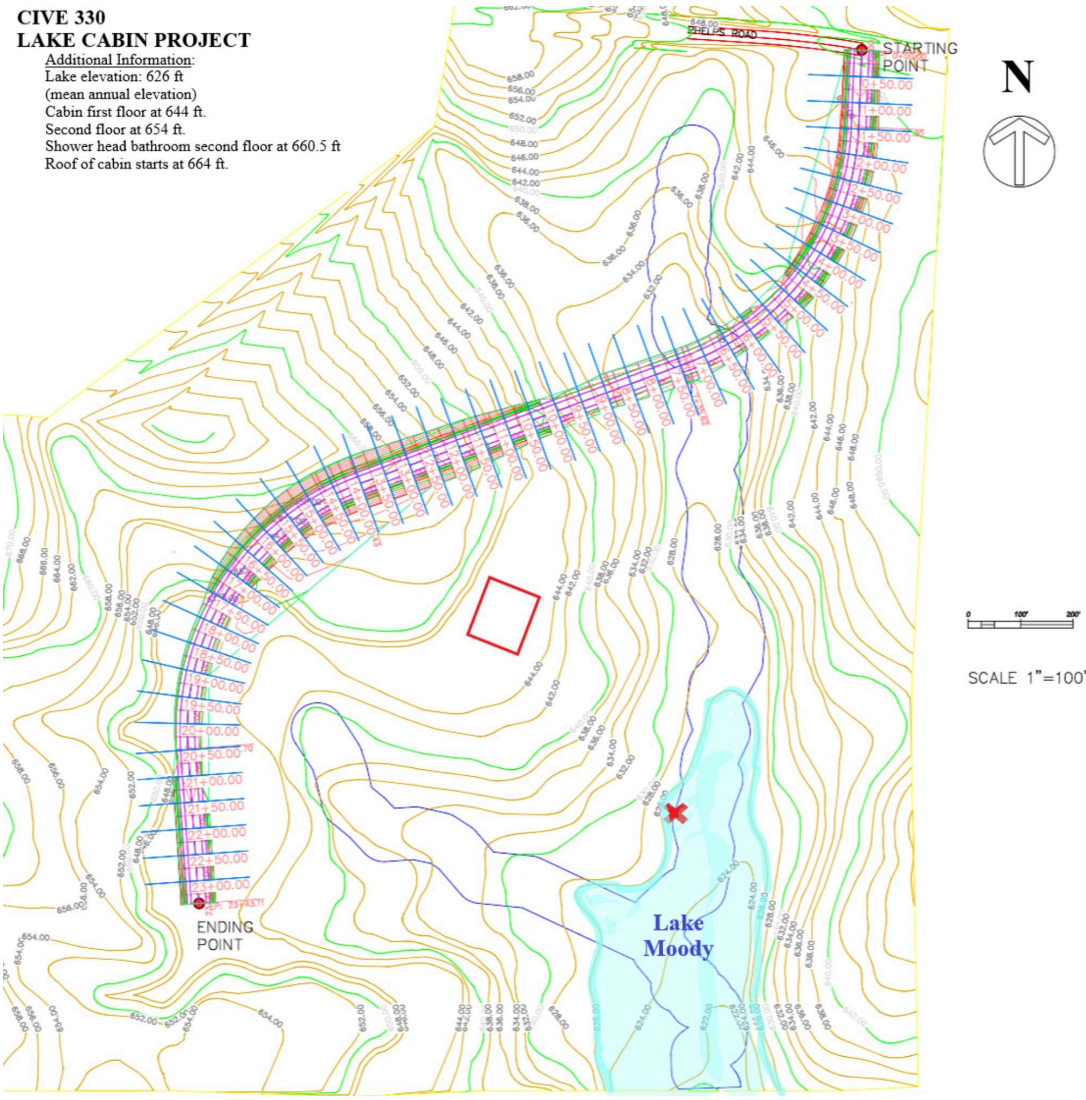

Figure 2. Topographical Diagram of Site

2.1. Appliances to Junction

The four appliances in the cabin were a washer, faucet, water heater and shower. The faucet and water heater were on the first floor and the shower and washer were on the second. The length of the pipe to each appliance varied depending on the distance from the junction, and the average demands were found online for each appliance.

The faucet had a pressure demand of 8 psi [1] and 2 gallons per minute [6]. A 1 inch diameter was assumed for the following calculations. The water heater had a pressure demand of 50-100 psi [3] and 7 gallons per minute [7]. A 3 inch diameter was assumed for the following calculations. The shower had a pressure demand of 8 psi [1] and 2 gallons per minute [6]. A 1 inch diameter was assumed for the following calculations. The washer had a pressure demand of 20-120 psi [4] and 2 gallons per minute [4]. A 1 inch diameter was assumed for the following calculations.

For each appliance, the following procedure was followed to calculate the head loss: (1) the velocity was calculated (Eq. 1) using the flow rate demanded and assumed diameter. The total flow rate, Q required for the appliances is 13 gallons per minute, which is used in later calculations to determine if there is sufficient flow rate into the house. **(5.1.5)**

$$Q = Av \qquad \textbf{(Eq 1)}$$

Using the roughness value for PVC (0.000005 ft) and the assumed diameter, the relative roughness was calculated and the Moody Chart was used to determine the Darcy friction factor. Then the f value determined alongside the velocity found in (Eq 1), the assumed diameter, and the kinematic viscosity of water was used to determine Reynold's Number **(Eq. 2)**.

$$R = \frac{VD}{v} \qquad \textbf{(Eq 2)}$$

This value was then used to determine a more accurate f value assuming turbulent conditions. Since this is a preliminary report, only one iteration was done, but for a more in depth analysis, more iterations could be completed to find the most accurate Darcy friction factor. The length for each appliance to the junction varied. The length from the junction to the faucet was 6 feet, the length from the junction to the water heater was 22 ft, the length from the junction to the shower was 18.5 ft, the length from the junction to the washer was 32 feet. **(Figure 1)** Using this more precise f value, assumed diameter, velocity and L value, the Darcy Weisbach Equation **(Eq 3)** can be used to calculate the head loss. The value of g=32.2 ft/s^2

$$h_L = f\frac{L}{D}\frac{v^2}{2g} \qquad \textbf{(Eq 3)}$$

After using (**Eq.3**) to determine the head loss from the junction to each appliance, it was calculated that the head loss to the faucet was 0.027 ft **(5.2)**, the head loss to the water heater was 0.103 ft **(5.3),** the head loss to the shower was 0.082 ft **(5.4)**, and the head loss to the washer was 0.142ft **(5.5).** The total head loss from the junction to each appliance is **0.354 ft.**

2.2. Junction to Tank

The next step was to analyze the junction to tank pressure, velocity and head loss. (Eq. 4) demonstrates the Q value needed to maintain a volumetric flow balance. Thus, the flow rate used in this section is 13 gallons per minute, as that was the flow determined was needed to supply the whole house.

$$\Sigma Q_{into\ junction} = \Sigma Q_{out\ of\ junction} \qquad \textbf{(Eq. 4)}$$

(**Eq. 1**) is used to determine the velocity which is 0.59 ft/s (**5.6**). The same procedure outlined in **Section 2.1** was used to find the head loss using Eq. 3. The head loss calculated was 0.008 ft **(5.6).**

Then, **(Eq. 5)** was used to determine the pressure at the junction. The pressure in the tank could be neglected, alongside the velocity as it was calculated as a large reservoir. The elevation at the junction was used as the datum and the elevation of the tank was used relative to that point. The pressure at the junction was calculated to be 0.19 psi **(5.6).**

$$\frac{P_{tank}}{\gamma} + \frac{v_{tank}^{2}}{2g} + z_{tank} = \frac{P_{junction}}{\gamma} + \frac{v_{junction}^{2}}{2g} + z_{junction} + h_{L} \qquad \textbf{(Eq. 5)}$$

2.3. Tank to Pump

The proper pump selection requires an evaluation of the tank-to-pump section of the system. Key variables of interest are the flow rate and head required by the system from the pump.

The flow rate that the pump generates must be great enough to ensure that when the floater in the storage tank indicates 10% capacity, the pump begins to fill the tank over the course of 2 hours. An additional constraint is that the tank must be large enough to supply the system for 1-2 days without any input from the reservoir. The total demand of the cabin (assuming constant flow for each appliance) is 13 GPM. It is assumed that maximum demand over a period of 16 hours is sufficient to represent the supply needed over 1 day, if not 2 or more. Therefore, 13 GPM was converted to GPH, and the volume for a period of 16 hours was found to be 12,480 gallons **(5.7)**.

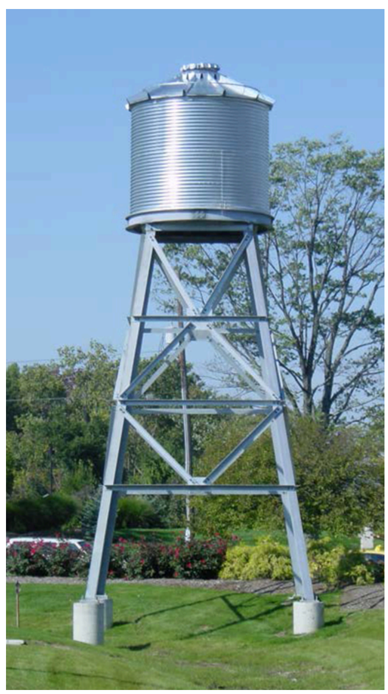

Figure 3. Representation of Appropriate Water Storage Tank [9]

To find the volume of water present when the tank is at 10% capacity, 10% of the total volume is considered, and it is found that the height of water at this volume is 1.8 ft **(5.7).** This is the height that the floater must be set to indicate at. To find the inflow rate necessary to fill the tank from this level, the difference of the total and 10% volumes (90%) is divided over 2 hours, and the flowrate is found to be 93.6 GPM **(5.7)**.

The head that the pump must overcome will rely on how much piezometric head and how much head loss the system has in this section. The total piezometric head to be overcome in this section is 45.5 ft. Bernoulli's equation **(Eq. 5)** is used to relate these values **(5.7)** and is then condensed to **(Eq.6):**

$$z_{tank} = \frac{P_{pump}}{\gamma} + h_L \quad \textbf{(Eq. 6)}$$

It is necessary to calculate the head loss due to friction in the system in order to find the pressure at the pump. This can be done using the Darcy Weisbach Equation **(Eq.3)** where f can be found using the Moody Diagram and the given roughness and pipe diameter of 1.5" PVC pipe. Velocity is found through relating the previously determined flow rate **(5.7)** and pipe area using **Eq. 1.** Substituting the rest of the values results in a head loss of 176.535 ft across the system spanning from the pump to the tank **(5.7)**. With this head loss, the pressure at the pump can be calculated. It is found that this is equivalent to 57.33 psi.

With the required flow rate and the pressure at the pump, the appropriate pump can be selected. The pump selected is the Grainger 3 hp, 208/230V AC Centrifugal Pump, 1 1/2 in Discharge [10]. This pump is suited for intake from open reservoir systems [8], and it is rated for a maximum flow rate of 105 GPM at 60 ft. of head. This lies well within our given system, where the demands are a maximum flow rate of 93.6 GPM at 45.5 ft of head. Another factor taken into consideration in this selection was the previously calculated **(5.7)** pressure at the pump. This model notes that the shut off pressure is rated at 75 psi. This means that the pump will only allow for pressures less than this maximum to continue operation. This system will have a maximum pump pressure of 57.33 psi, therefore within the capacity of this model.

Figure 4. Selected Pump, Grainger 208/230V Centrifugal Pump [10]

2.4 Bill of Materials

The following is a cost estimate for the water storage network discussed herein. This estimate is based solely on material cost, however labor and transportation costs would be considered once further pursuing this project.

Item	Cost	Amount/Length	Total
1” PVC Pipe [12]	$8.48/10 ft.	58.5 ft	$49.61
3” PVC Pipe [13]	$23.94/10 ft.	49.5 ft	$118.51
1.5” PVC Pipe [14]	$12.78/10 ft.	468.87 ft	$599.22
Tank [11]	$17,000	1 unit	$17,000
Pump [10]	$1,873.52	1 unit	$1,873.52
-	-	**Total Estimate**	$19,640.86

3. Conclusions

The design for the property’s water supply system has been discussed herein. Key considerations that were addressed include the height of the water tower supply tank, the volume of tank needed to ensure independent operation for 1-2 days, and the pump necessary to transport water from the reservoir to the tank. The system was outlined in Figure 1, representing a detailed strategy for addressing the system’s demands.

Most notably, appropriate tank and pump selections were made, supported by relevant calculations such as head losses and pipe flow velocities. In order to meet the needs of the desired system, the following key elements are required: a 12,480 gallon water storage tank, elevated to a height of 25.5 ft. above the base of the house (45.5 ft above datum), and a 3 hp, 208/230V, Centrifugal Pump pulling from the noted reservoir, as well as approximately 577 ft of PVC pipe of varying diameter. The material cost of this system is estimated to be $19,640.86 **(2.4).**

Please contact us for further details in pursuing this project, and don’t hesitate to reach out with any questions. Thank you for your interest in our services.

4. References

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[10] “3 HP, 208/230v AC, Centrifugal Pump.” Grainger, https://www.grainger.com/product/GOULDS-WATER-TECHNOLOGY-Centrifugal-Pump-3-hp-784RN0

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5. Appendix

5.1. Term definition

Prior to delving into the calculation portion, the following section has been provided to define all variables needed for this report.

$Q\ =\ flow\ rate\ of\ water$

$A\ =\ cross\ sectional\ area\ of\ the\ pipe$

$v\ =\ velocity\ of\ the\ water\ flowing\ through\ pipe$

$e\ =\ roughness\ of\ the\ pipe$

$d\ =\ diameter\ of\ the\ pipe$

$R\ =\ Reynold's\ Number$

$v\ =\ viscosity$

$f\ =\ Darcy\ friction\ factor$

$h_l =\ head\ loss$

$L\ =\ length\ of\ pipe$

5.2. Faucet Head Loss Calculations

This section focuses on calculating the velocity and head loss for the junction to faucet where the L=6 ft **(Figure 1).**

Velocity

$Q\ =\ Av$

$(0.267\ ft^3/min)\ =\ (0.00548\ ft^2)(v)$

$Velocity\ =\ 48.722\ ft/min\ =\ 0.812\ ft/sec$

f value

$\frac{e}{D} = \frac{0.000005\ ft}{0.0833333\ ft} =\ 6\ x\ 10^{-5}$

$f\ =\ 0.011$

Reynolds Number

$R\ = \frac{VD}{v} = \frac{(0.812\ ft/sec)(0.083\ ft)}{(0.000010789\ ft^2/s)} =\ 6.2\ x\ 10^3$

New f value

$f\ =\ 0.036$

Head Loss

$h_L\ = f\frac{L}{D}\frac{v^2}{2g}$

$$h_L = (0.036)\frac{(6\,ft)}{(0.083\,ft)}\frac{(0.812\,ft/sec)^2}{2\,(32.2\,ft/s^2)}$$

$$h_L = 0.027\,ft$$

5.3. Water Heater Head Loss

This section focuses on calculating the velocity and head loss for the junction to the water heater where the L=22 ft **(Figure 1).**

Velocity:

$$Q = Av$$

$$(0.936\,ft\char`^3/min) = (0.049\,ft\char`^2)(v)$$

$$Velocity = 19.08\,ft/min = 0.318\ \ ft/s$$

f value

$$\frac{e}{D} = \frac{0.000005\,ft}{0.049\,ft} = 0.000102$$

$$f = 0.0119$$

Reynolds Number

$$R = \frac{VD}{v} = \frac{(0.318\ \ ft/sec)(0.25\,ft)}{(0.000010789\,ft^2/s)} = 7.3\,x\,10^3$$

New f value

$$f = 0.038$$

Head Loss

$$h_L = f\frac{L}{D}\frac{v^2}{2g}$$

$$h_L = (0.038)\frac{(22\,ft)}{(0.083\,ft)}\frac{(0.812\,ft/sec)^2}{2\,(32.2\,ft/s^2)}$$

$$h_L = 0.103\,ft$$

5.4. Shower Head Loss

This section focuses on calculating the velocity and head loss for the junction to the shower where the L=18.5 ft **(Figure 1).**

Velocity:

$$Q = Av$$

$$(0.267\,ft^3/min) = (0.00548\,ft^2)(v)$$

$$Velocity = 48.722\,ft/min = 0.812\,ft/sec$$

f value

$$\frac{e}{D} = \frac{0.000005\,ft}{0.0833333\,ft} = 6\,x\,10^{-5}$$
$$f = 0.011$$

Reynolds Number

$$R = \frac{VD}{v} = \frac{(0.812\,ft/sec)(0.083\,ft)}{(0.000010789\,ft^2/s)} = 6.2\,x\,10^3$$

New f value

$$f = 0.036$$

Head Loss

$$h_L = f\frac{L}{D}\frac{v^2}{2g}$$
$$h_L = (0.036)\frac{(18.5\,ft)}{(0.083\,ft)}\frac{(0.812\,ft/sec)^2}{2\,(32.2\,ft/s^2)}$$
$$h_L = 0.082\,ft$$

5.5. Washer Head Loss

This section focuses on calculating the velocity and head loss for the junction to the washer where the L=32 ft **(Figure 1).**

Velocity:

$$Q = Av$$
$$(0.267\,ft^3/min) = (0.00548\,ft^2)(v)$$
$$Velocity = 48.722\,ft/min = 0.812\,ft/sec$$

f value

$$\frac{e}{D} = \frac{0.000005\,ft}{0.0833333\,ft} = 6\,x\,10^{-5}$$
$$f = 0.011$$

Reynolds Number

$$R = \frac{VD}{v} = \frac{(0.812\,ft/sec)(0.083\,ft)}{(0.000010789\,ft^2/s)} = 6.2\,x\,10^3$$

New f value

$$f = 0.036$$

Head Loss

$$h_L = f\frac{L}{D}\frac{v^2}{2g}$$

$$h_L = (0.036)\frac{(32\,ft)}{(0.083\,ft)}\frac{(0.812\,ft/sec)^2}{2\,(32.2\,ft/s^2)}$$
$$h_L = 0.142\,ft$$

5.6. Junction to tank

This section focuses on calculating the velocity and head loss for the junction to the tank where the L=36.5 ft **(Figure 1).**

Velocity

$$Q = Av$$
$$13\,GPM\,(\frac{0.002228\,ft^3/s}{1\,GPM}) = (\frac{\pi}{4})(3\,in)^2(\frac{1\,ft}{12\,in})^2(v)$$
$$v = 0.59\,ft/s$$

Head Loss

$$h_L = f\frac{LV^2}{D2g}$$
$$\frac{e}{D} = \frac{0.00006\,in}{1.5\,in} = 0.00004$$
f=0.0105
$$h_L = (0.0105)\frac{(36.5ft)(0.59\,ft/s)^2}{(3in)(\frac{1\,ft}{12\,in})2(32.2\,ft/s^2)} = 0.008\,ft$$

Pressure

$$\frac{P_{tank}}{\gamma} + \frac{v_{tank}^2}{2g} + z_{tank} = \frac{P_{junction}}{\gamma} + \frac{v_{junction}^2}{2g} + z_{junction} + h_L$$
$$z_{tank} = \frac{P_{junction}}{\gamma} + \frac{v_{junction}^2}{2g} + h_L$$
$$27.5\,ft = \frac{P_{junction}}{63\,lb/ft^3} + \frac{(0.59\,ft/s)^2}{2(32.2\,ft/s^2)} + 0.008\,ft$$

$$P_{junction} = 27.48\,lb/ft^3 = 0.19\,psi$$

5.7. Tank to Pump

This section focuses on calculating the velocity and head loss for the tank to the pump where the L= 468.87 ft **(Figure 1).**

Total Volume of Tank

$$13\,GPM(\frac{60\,min}{1\,hr})(16hr) = 12,480\,gal$$

Elevation of water in tank at 10% Capacity

Diameter - 12 ft [9]

12480 gal = 1668 ft3; Vol (10%) = 166.8 ft3

$$h = \frac{V}{\pi(D/2)^2}$$

h = 18 ft.

h @ 10% = 1.8 ft.

Flow Rate for Pump to Fill Tank Within 2 hr

12480 gal - 1248 gal = 11232 gal

11232 gal / 2 hr = 5616 gal / hr = **93.6 GPM**

Head Loss Due to Friction

$$\frac{e}{D} = \frac{0.00006\ in}{1.5\ in} = 0.00004$$

f=0.0105 (Moody)

$$93.6\ GPM\left(\frac{0.002228\ ft^3/s}{1\ GPM}\right) = \left(\frac{\pi}{4}\right)(1.5\ in)^2\left(\frac{1\ ft}{12\ in}\right)^2(v)$$

$$v = 16.99\ ft/s$$

$$h_L = (0.0105)\frac{(468.87ft)(16.99\ ft/s)^2}{(1.5in)\left(\frac{1\ ft}{12\ in}\right)2(32.2\ ft/s^2)} = 176.535\ ft$$

Pressure at Pump

$$\frac{P_{tank}}{\gamma} + \frac{v_{tank}^2}{2g} + z_{tank} = \frac{P_{pump}}{\gamma} + \frac{v_{pump}^2}{2g} + z_{pump} + h_L$$

$$z_{tank} = \frac{P_{pump}}{\gamma} + h_L$$

$$45.5\ ft = \frac{P_{pump}}{63\ lb/ft^3} + h_L$$

$$45.5\ ft = \frac{P_{pump}}{63\ lb/ft^3} + 176.535ft$$

$$P_{pump} = 8255\ lb/ft^2 = 57.33\ psi$$