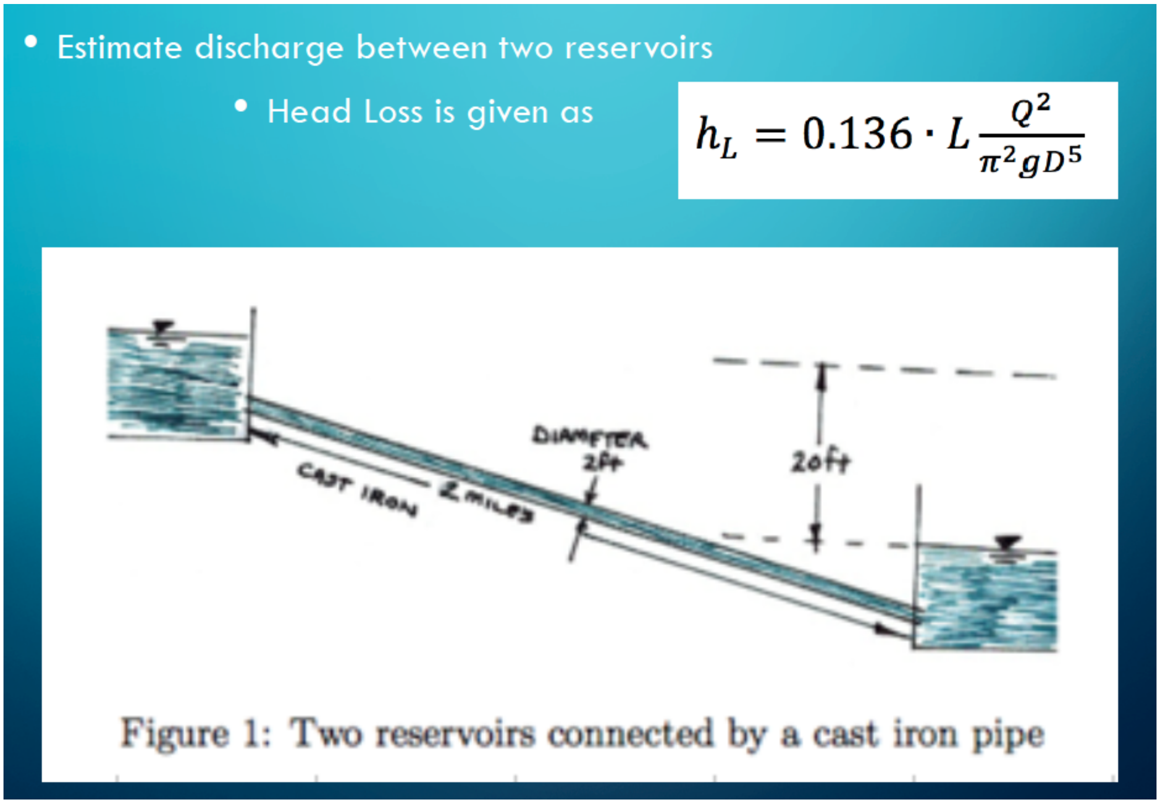
5. CE 3372 Lesson 5 – Pipeline Hydraulics

5.1. Single Path Pipelines

5.1.1. Gravity Flow Between Two Reservoirs

Figure 6 is a schematic of two reservoirs connected by a pipeline. In the sketch, the reservoirs are connected below their pool elevations at each end, so water will flow from the upper reservoir to the lower reservoir as long as water is available. This is a fairly classical problem, and the head los model in the figure is a Darcy-Weisbach model with a fairly high friction factor.



- Estimate discharge between two reservoirs
  - Head Loss is given as

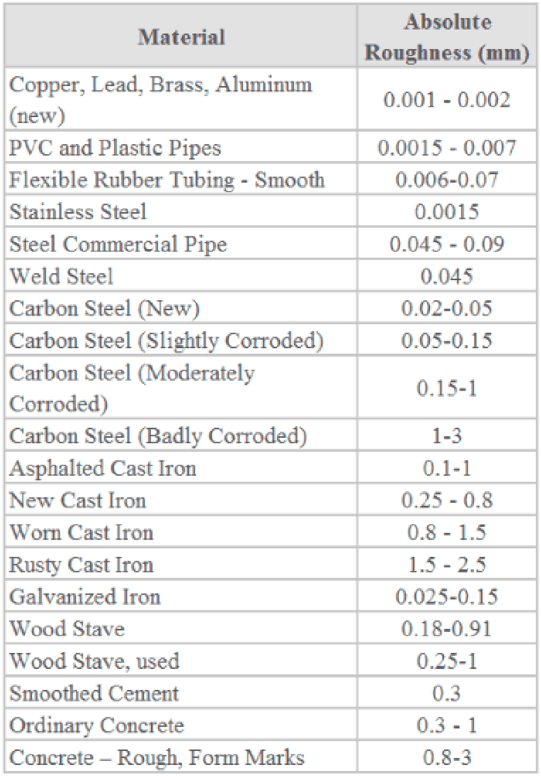
$$h_L = 0.136 \cdot L \frac{Q^2}{\pi^2 g D^5}$$

Figure 1: Two reservoirs connected by a cast iron pipe

Figure 6. Water Supply System in Re-Developing Nation.

In class we will analyze using the Modified Bernoulli equation, then we can compare that result to the on-line toolkit.

For this example, we need the roughness height in feet (or the diameter in meters). Figure 7 is the result of a Google search for roughness height. The online source is `https://www.nuclear-power.net/nuclear-engineering/fluid-dynamics/major-head-loss-friction-loss/relative-roughness-of-pipe/`



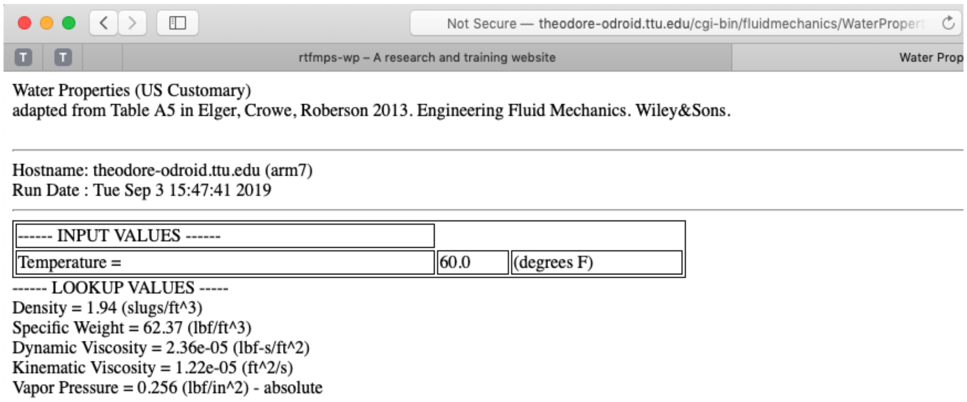
Material	Absolute Roughness (mm)
Copper, Lead, Brass, Aluminum (new)	0.001 - 0.002
PVC and Plastic Pipes	0.0015 - 0.007
Flexible Rubber Tubing - Smooth	0.006-0.07
Stainless Steel	0.0015
Steel Commercial Pipe	0.045 - 0.09
Weld Steel	0.045
Carbon Steel (New)	0.02-0.05
Carbon Steel (Slightly Corroded)	0.05-0.15
Carbon Steel (Moderately Corroded)	0.15-1
Carbon Steel (Badly Corroded)	1-3
Asphalted Cast Iron	0.1-1
New Cast Iron	0.25 - 0.8
Worn Cast Iron	0.8 - 1.5
Rusty Cast Iron	1.5 - 2.5
Galvanized Iron	0.025-0.15
Wood Stave	0.18-0.91
Wood Stave, used	0.25-1
Smoothed Cement	0.3
Ordinary Concrete	0.3 - 1
Concrete – Rough, Form Marks	0.8-3

Figure 7. Absolute Roughness Height for Some Common Pipe Materials..

The roughness height is determined from:

$$k_s = 0.8mm \times \frac{1\ inch}{25.4\ mm}\frac{1\ foot}{12\ inch} = 0.00262\ feet \tag{2}$$

Next we will need the water viscosity – we look that value up in a properties table such as Appendix C of the textbook or using an on-line tool as in Figure 8



Water Properties (US Customary)
adapted from Table A5 in Elger, Crowe, Roberson 2013. Engineering Fluid Mechanics. Wiley&Sons.

Hostname: theodore-odroid.ttu.edu (arm7)
Run Date : Tue Sep 3 15:47:41 2019

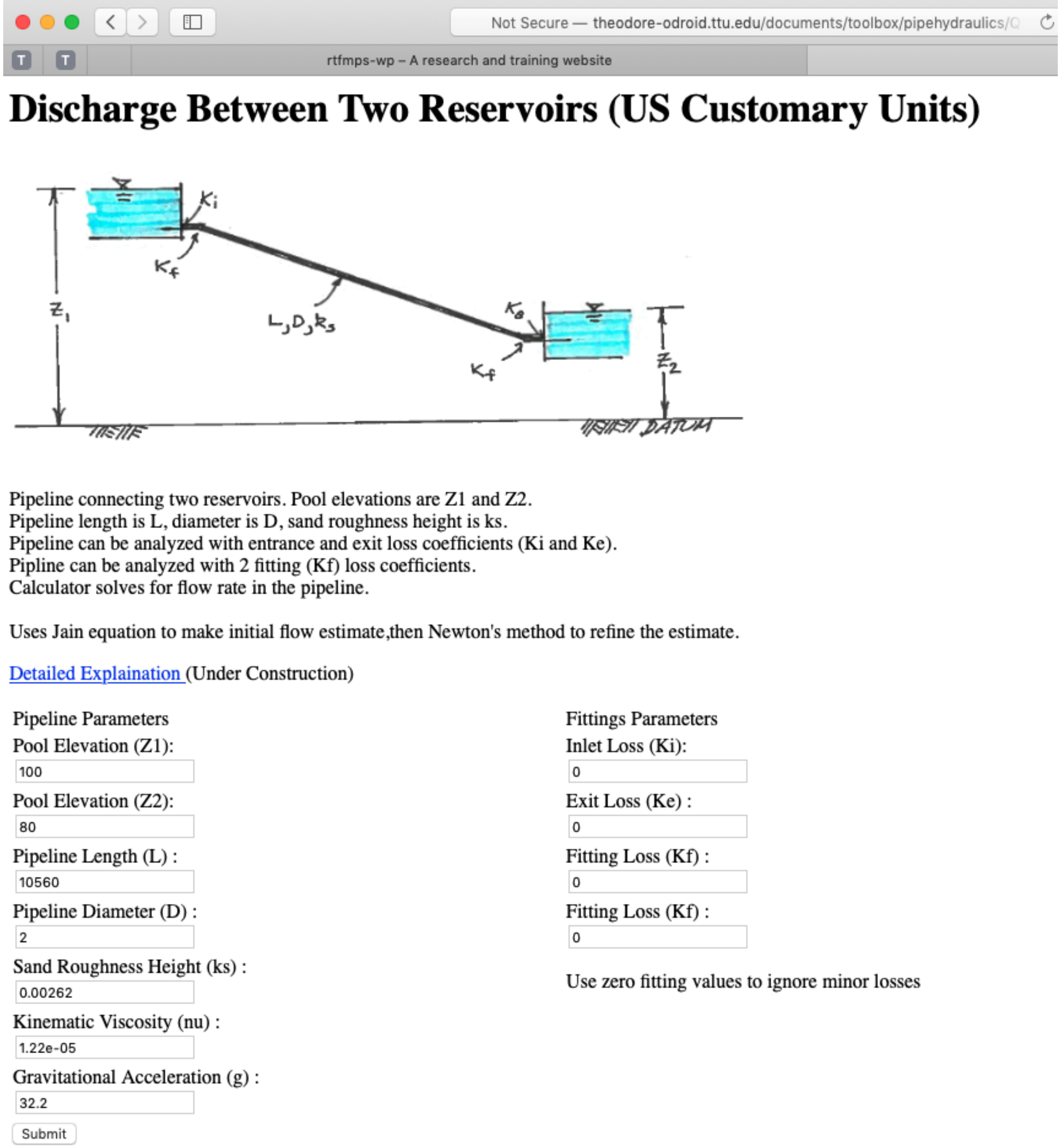
------ INPUT VALUES ------		
Temperature =	60.0	(degrees F)

------ LOOKUP VALUES -----
Density = 1.94 (slugs/ft^3)
Specific Weight = 62.37 (lbf/ft^3)
Dynamic Viscosity = 2.36e-05 (lbf-s/ft^2)
Kinematic Viscosity = 1.22e-05 (ft^2/s)
Vapor Pressure = 0.256 (lbf/in^2) - absolute

Figure 8. Water Properties at 60 degrees Farenheight.

The remaining information is contained in Figure 6. The next step is to apply an appropriate model (here we will use the on-line Jain models) to estimate the discharge.

Figure 9 is a screen capture of the input form.



Discharge Between Two Reservoirs (US Customary Units)

Pipeline connecting two reservoirs. Pool elevations are Z1 and Z2.
Pipeline length is L, diameter is D, sand roughness height is ks.
Pipeline can be analyzed with entrance and exit loss coefficients (Ki and Ke).
Pipline can be analyzed with 2 fitting (Kf) loss coefficients.
Calculator solves for flow rate in the pipeline.

Uses Jain equation to make initial flow estimate,then Newton's method to refine the estimate.

Detailed Explaination (Under Construction)

Pipeline Parameters
Pool Elevation (Z1): 100
Pool Elevation (Z2): 80
Pipeline Length (L) : 10560
Pipeline Diameter (D) : 2
Sand Roughness Height (ks) : 0.00262
Kinematic Viscosity (nu) : 1.22e-05
Gravitational Acceleration (g) : 32.2

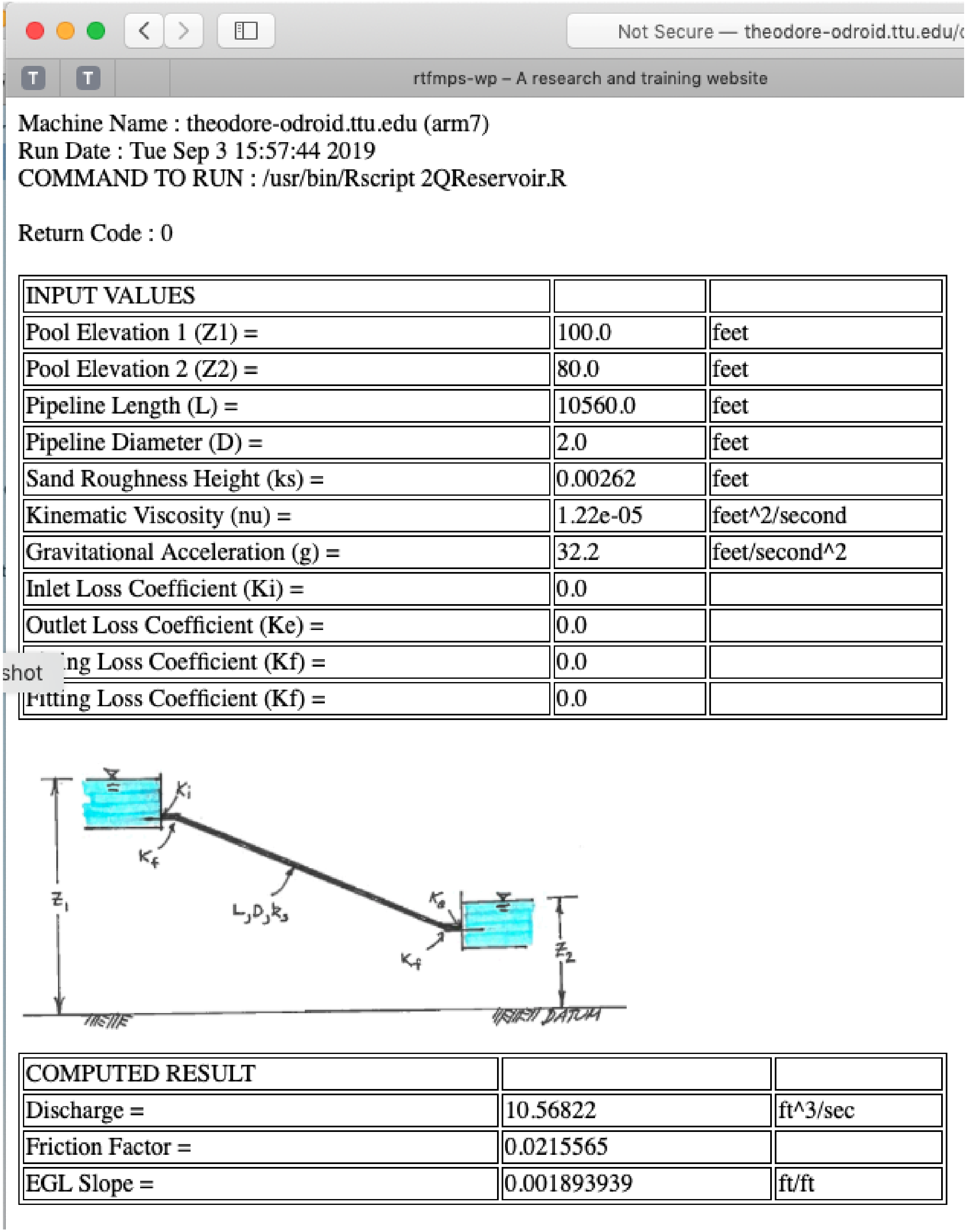
Fittings Parameters
Inlet Loss (Ki): 0
Exit Loss (Ke) : 0
Fitting Loss (Kf) : 0
Fitting Loss (Kf) : 0

Use zero fitting values to ignore minor losses

Figure 9. Input Form for Flow Between Two Reservoirs.

In the example all the fitting losses are set to zero, but they are easily incoprorated if necessary. Next we select the submit button to run the calculator.

Figure 10 is the response from the calculator. In this example the anticipated discharge is about 10.5 cubic feet per second.



```
Machine Name : theodore-odroid.ttu.edu (arm7)
Run Date : Tue Sep 3 15:57:44 2019
COMMAND TO RUN : /usr/bin/Rscript 2QReservoir.R

Return Code : 0
```

INPUT VALUES		
Pool Elevation 1 (Z1) =	100.0	feet
Pool Elevation 2 (Z2) =	80.0	feet
Pipeline Length (L) =	10560.0	feet
Pipeline Diameter (D) =	2.0	feet
Sand Roughness Height (ks) =	0.00262	feet
Kinematic Viscosity (nu) =	1.22e-05	feet^2/second
Gravitational Acceleration (g) =	32.2	feet/second^2
Inlet Loss Coefficient (Ki) =	0.0	
Outlet Loss Coefficient (Ke) =	0.0	
ng Loss Coefficient (Kf) =	0.0	
Fitting Loss Coefficient (Kf) =	0.0	

COMPUTED RESULT		
Discharge =	10.56822	ft^3/sec
Friction Factor =	0.0215565	
EGL Slope =	0.001893939	ft/ft

Figure 10. Input Form for Flow Between Two Reservoirs.

5.1.2. Pumped Flow Between Two Reservoirs

5.2. Linking Systems

Figure 11 is an aerial image of a pipeline system with preliminary engineering sketches of the system (lower left panel) and a detail sketch of the terminal small storage tank (upper right panel). The 3,200 meter long pipeline lifts 25C water ($\rho = 997\ kg/m^3$, $\nu = 8.94 \times 10^{-7}\ m^2/s$) from a treatment plant on the downstream face of Gulameta Dam through a 127 millimeter high-density polyethylene (HDPE) pipe ($k_s = 0.0015\ mm$) to a large diameter at-grade cylindrical storage tank. A secondary, 800 meter long pipeline carries water from the large diameter storage tank to a small, cylindrical ($D = 1\ meter$), elevated storage tank at the village school. Both storage tanks have float valves to prevent overflow and maintain the indicated water pool elevations.

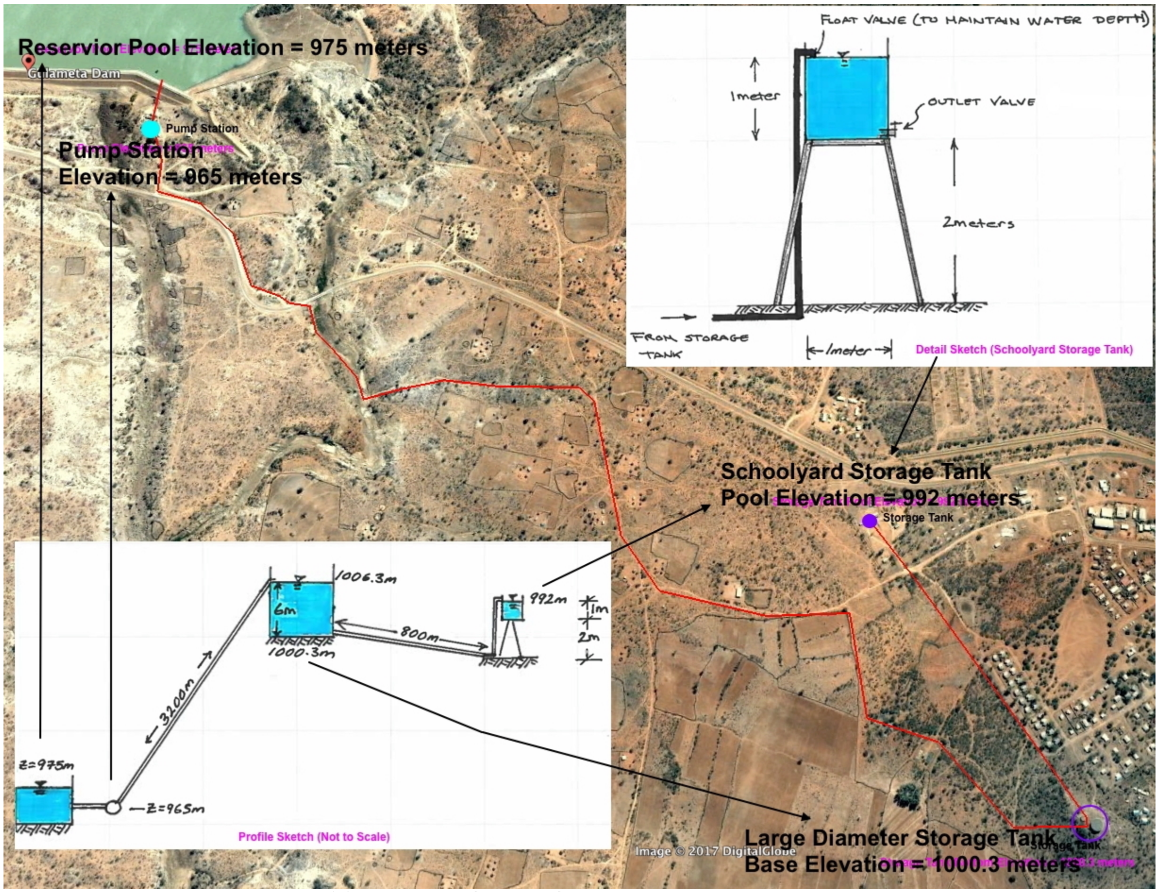


Figure 11. Water Supply System in Re-Developing Nation.

We will analyze the system under a couple of conditions to determine its anticipated behavior. Assume the float valve at the schoolyard fails in the open position, and the schoolyard tank overflows. Using the Modified Bernoulli (Energy) Equation for the portion of the system from the large diameter storage tank to the schoolyard storage tank, and neglecting minor loss terms (but not the pipeline loss), determine the flow rate in the system in Liters-per-second. Using the flow rate just computed, and the Modified Bernoulli (Energy) Equation for the portion of the system from from the water supply reservoir (Lake Gulameta) to the large diameter storage tank, and neglecting minor loss terms (but not the pipeline loss), determine the required pump head (added head). Assume the float valve at the schoolyard is operating normally, but someone accidentally leaves the outlet valve (nominal diameter = 50 mm) from the tank open. Estimate the required flow rate in the system in Liters-per-second to sustain the indicated pool elevations.

Figure 12 is a set of pump curves for a pump at different impeller speeds. Circle the portion of the graphic that contains information about the Net Positive Suction Head (NPSH) required by the pump. Assuming the schoolyard overflow condition is the most flow the pump will have to deliver, select a pump speed from one of the five on Figure 12 below. Indicate which curve you selected, show the operating point. Indicate if you need two pumps in series to supply the necessary head. Estimate the NPSH required for the pump at your operating point.

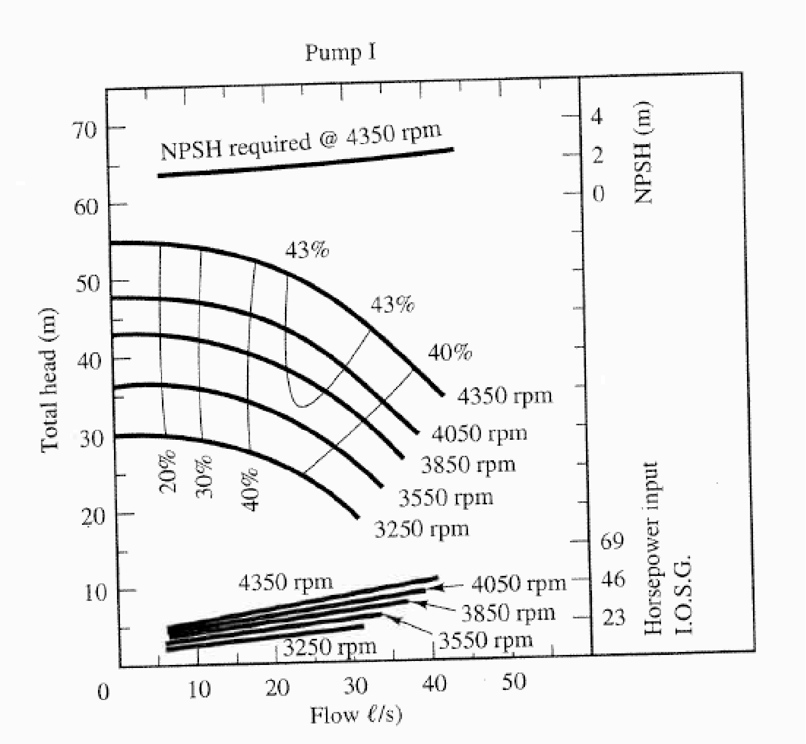


Figure 12. Pump curves for 5 different impeller speeds..

Estimate the NPSH available for the system, you can neglect inlet piping and minor losses. Assume the water is at 25 degrees Celsius.

Is there sufficient NPSH available for the system to function at the design flow rate without cavitation?