CE 3372 – Water Systems Design
Exercise Set 4

Purpose: Review and application of head loss models used in water transmission and distribution system analysis

Exercises

1. Equation **??** is the Hazen-Williams discharge formula in US Customary Units.

$$Q = 1.318 C_h A R^{0.63} S^{0.54} \tag{1}$$

where;
Q is the discharge in ft^3/sec;
A is the cross section area of pipe in ft^2 ($A = \frac{\pi D^2}{4}$; D is the pipe diameter.);
C_h is the Hazen-Williams friction coefficient (depends on pipe roughness);
R is the hydraulic radius in ft; and
S is the slope of the energy grade line ($\frac{h_f}{L}$); L is the length of pipe.

(a) Look up the Hazen-Williams loss coefficient (C_h) for enamel coated, steel pipe and cite your data source.

(b) Estimate the head loss in a 10,000 foot length of 5-foot diameter, enamel coated steel pipe that carries carries 60^oF water at a discharge of 295 cubic-feet per second (cfs), using the Hazen-Williams head loss model.

2. Equation **??** is the Hazen-Williams discharge formula in SI Units.

$$Q = 0.849 C_h A R^{0.63} S^{0.54} \tag{2}$$

where;
Q is the discharge in m^3/sec;
A is the cross section area of pipe in m^2 ($A = \frac{\pi D^2}{4}$; D is the pipe diameter.);
C_h is the Hazen-Williams friction coefficient (depends on pipe roughness);
R is the hydraulic radius in m; and
S is the slope of the energy grade line ($\frac{h_f}{L}$); L is the length of pipe.

(a) Look up the Hazen-Williams loss coefficient (C_h) for Acrylonite Butadiene Styrene (ABS) pipe and cite your data source.

(b) Estimate the head loss in a 3,050 meter length of 1.5-meter diameter, ABS pipe that carries carries 20^oC water at a discharge of 8.35 cubic-meters per second (cms), using the Hazen-Williams head loss model.

3. Equation **??** is an explicit formula (based on the Darcy-Weisbach head loss model and the Colebrook-White frictional loss equation)for estimating discharge from head loss and material properties (**?**).

$$Q = -2.22D^{5/2} \times \sqrt{gh_f/L} \times [log_{10}(\frac{k_s}{3.7D} + \frac{1.78\nu}{D^{3/2}\sqrt{gh_f/L}})] \tag{3}$$

where;

Q is the discharge in L^3/T;
D is the pipe diameter;
h_f is the head loss in the pipe;
g is the gravitational acceleration constant;
L is the length of pipe;
k_s is the pipe roughness height;
ν is the viscosity of liquid in the pipe;

(a) Find the viscosity for water at 50^{o}F. Cite the source of your value.

(b) Find the sand roughness height of ductile iron pipe. Cite the source of your value.

(c) How deep is a column of water if the pressure at the bottom of the column is 20 psi?

(d) Estimate the discharge in the 3 mile long, 24-inch diameter, ductile iron pipeline connecting points A and B depicted in Figure **??**. Point A is 30 feet higher in elevation than point B. The pressure at point B is 20 pounds per square-inch (psi) greater than the pressure at point A.

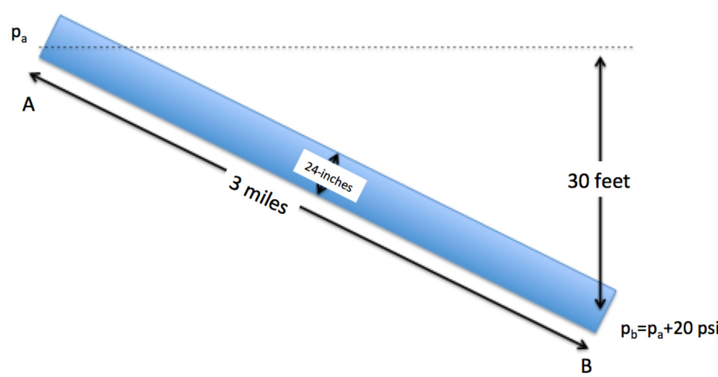


Figure 1: Pipeline Schematic

4. Equation **??** is a formula to estimate the required pipe diameter for a particular discharge, head loss, and roughness (**?**).

$$D = 0.66[k_s^{1.25} \times (\frac{LQ^2}{gh_f})^{4.75} + \nu Q^{9.4} \times (\frac{L}{gh_f})^{5.2}]^{0.04} \quad (4)$$

where;

D is the pipe diameter;
k_s is the pipe roughness height;
L is the length of pipe;
g is the gravitational acceleration constant;
Q is the discharge in L^3/T;
h_f is the head loss in the pipe;
ν is the viscosity of liquid in the pipe;

(a) Find the viscosity for water at 60^oF. Cite the source of your value.

(b) Find the sand roughness height of cast-iron pipe. Cite the source of your value.

(c) Estimate the diameter of a cast-iron pipe needed to carry 60^oF water at a discharge of 10 cubic-feet per second (CFS) between two reservoirs 2 miles apart with an elevation difference between the water surfaces in the two reservoirs of 20 feet as depicted in Figure **??**.

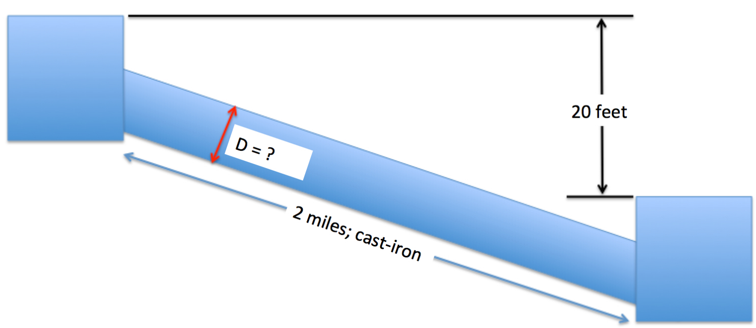


Figure 2: Pipeline connecting two reservoirs

5. Figure **??** is an aerial image of a parallel pipeline system in California.

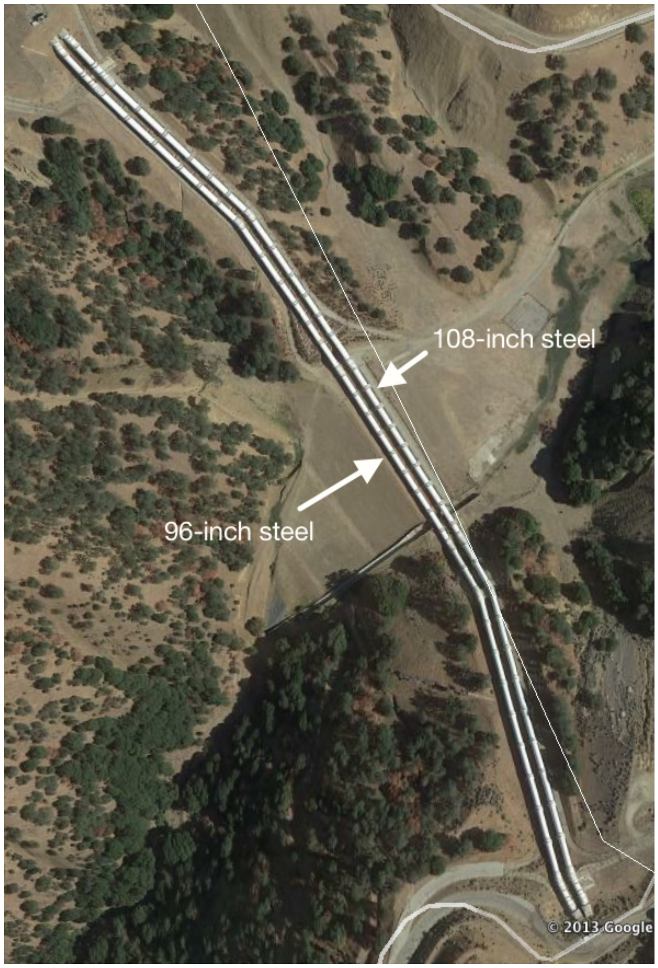


Figure 3: Parallel Pipeline System

The left pipeline is a 96-inch diameter steel pipe, whereas the right pipeline is a 108-inch diameter steel pipe. Water at 50^{o}F has kinematic viscosity of $1.45 \times 10^{-5}\ ft^2/s$. The sand roughness of ductile iron is $1.64 \times 10^{-4}\ ft$. If the head difference for the one-mile long pipelines between the thrust blocks is 120 feet, determine the discharge in each pipe in cubic-feet-per-second.

References

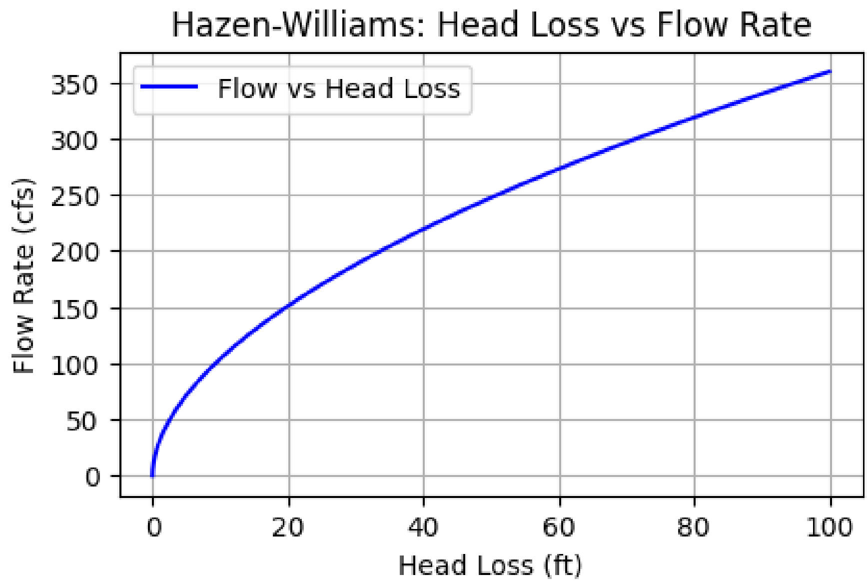
Swamee and Jain, A. K., 1976. Explicit equations for pipe-flow problems. ASCE J. of Hyd. Div., 102(HY5) pp. 657-664

ES4-P1

February 16, 2025

[66]:
```python
# ES4 Problem 1
# Hazen Williams US Customary
def flowhw(coef, diameter, slope):
    import math
    area = 0.25 * math.pi * diameter**2
    radius = diameter / 4.0
    flowhw = 1.318 * coef * area * (radius**0.63) * (slope**0.54)
    return flowhw

import matplotlib.pyplot as plt
# Parameters
length = 10000  # ft
diameter = 5  # ft
ch = 145  # Hazen-Williams coefficient (Enamel/epoxy look up online)
# Initialize variables
howMany = 10000  # search region
head_loss_values = [0 for i in range(howMany)]
for i in range(howMany):
    head_loss_values[i]=i/100 # search increment
flow_values = []
# Calculate flow rates for each head_loss
for head_loss in head_loss_values:
    slope = head_loss / length
    flow_values.append(flowhw(ch, diameter, slope))
# Plot head_loss vs flow
plt.figure(figsize=(5, 3))
plt.plot(head_loss_values, flow_values, label="Flow vs Head Loss", color="blue")
plt.title("Hazen-Williams: Head Loss vs Flow Rate")
plt.xlabel("Head Loss (ft)")
plt.ylabel("Flow Rate (cfs)")
plt.grid(True)
plt.legend()
plt.show()
```



[67]:
```
def find_closest_index(lst, target):
    return min(range(len(lst)), key=lambda i: abs(lst[i] - target))

# Example Usage
target_value = 295
index = find_closest_index(flow_values, target_value)
print(f"The index of the closest value to {target_value} is {index}.")
print(f"The closest value is {flow_values[index]}.")
print(f"The head loss is {head_loss_values[index]}.")
```

```
The index of the closest value to 295 is 6944.
The closest value is 295.0094006816501.
The head loss is 69.44.
```

[ ]:
```

```

ES4-P1

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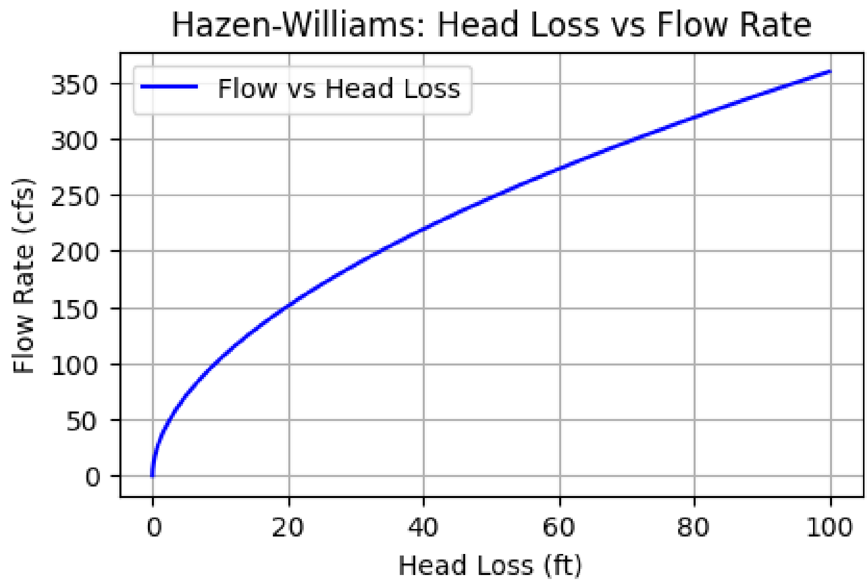

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