Name: ____

CVEN 458 – Hydraulic Engineering of WDS
Spring Semester 2013
Dr. Kelly Brumbelow, Texas A&M University

Exam #1 – Part A

<u>Closed-book, Closed-notes (2 pages, 3 questions in this part); Time allowed: 20 minutes</u>
All work for Part A must be written on the Part A pages.

1. For the following elements, state whether a thrust block/restraint would be needed and the direction of force that the block/restraint would exert on the element. (You may draw a sketch, if necessary to explain your answer). *(3 points each)*

(a) 45° bend

(b) Isolation valve (straight pipe connected to both sides of valve)

(c) Reducer coupling (e.g., connection between 8 inch and 12 inch diameter pipe sections)

(d) Pressure reducing valve

2. A journalist from a local media outlet approaches you one day and says that he has recently learned that the local water distribution system is filled with “hazardous asbestos piping.” He asks for your comment as an experienced water resources engineer. What do you tell him? *(6 points)*

3. Your firm is preparing a conceptual design for a small municipal water utility considering future expansion. The design is for a 12 inch diameter water main, 3 miles long, to be installed for expected future growth outside the city’s currently developed footprint. The utility has explicitly communicated to your firm that its highest priority for the design is “minimal uncertainty in estimated cost of project.” A colleague, noticing that the main will cross a high voltage power line easement at one point, has suggested that the entire main be PVC to minimize stray voltage corrosion concerns. Does this seem like the best possible choice for pipe material? Explain your answer. *(6 points)*

CVEN 458 – Hydraulic Engineering of WDS
Spring Semester 2013
Dr. Kelly Brumbelow, Texas A&M University

Exam #1 – Part B

<u>Open-book, Open-notes (2 pages [+ ref sheets], 2 questions); Time allowed: 55 minutes</u>
All work for Part B must be written on separate pages with your name written on each page.

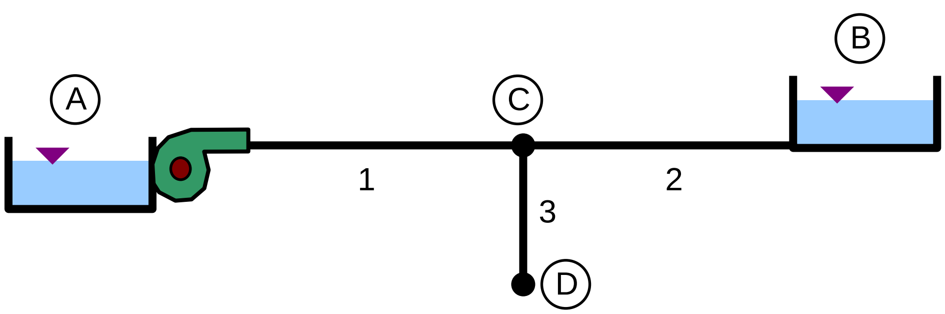
1. A small WDS is diagrammed and relevant parameters are defined below. Attached to the exam are look-up tables and reference material that you may find helpful.

   (a) Determine flows (gpm) in the 3 pipes and heads (ft) at nodes C and D using the **Darcy-Weisbach** head loss formula and the **Swamee-Jain** equation. You may <u>not</u> assume wholly turbulent flow in your calculations, and you may not use the Moody diagram.

   (b) Determine flows (gpm) in the 3 pipes and heads (ft) at nodes C and D using the **Hazen-Williams** head loss formula.

   (c) Discuss the similarities and differences in your solutions from parts (a) and (b). Are these similarities and differences consistent with our class discussion of the two head loss formulae?

(46 points)



HGL_A = 250.0 ft; HGL_B = 335.0 ft; Dem_C = 175 gpm; Dem_D = 65 gpm

Pipes 1 and 2: L = 1000 ft, D = 12 in, PVC; Pipe 3: L = 700 ft, D = 6 in, New uncoated cast iron

Pump characteristic equation: $E_p = -0.0001Q^2 - 0.05Q + 140$, [Ep] = ft, [Q] = gpm
$E_p = -20.145Q^2 - 22.4Q + 140$, [Ep] = ft, [Q] = cfs

1 cfs = 448.83 gpm

2. For the WDS in problem 1, *do all necessary work to setup the first iteration of the Gradient Method solution for flows and heads in this network using the* ***Hazen-Williams*** *equation for all pipe head losses.* Your final answer should be the matrix equation:

$$\begin{bmatrix} n\underline{A_{11}} & \underline{A_{12}} \\ \underline{A_{21}} & \underline{0} \end{bmatrix} \times \begin{bmatrix} \underline{\Delta Q} \\ \underline{\Delta H} \end{bmatrix} = \begin{bmatrix} -\underline{dE} \\ -\underline{dq} \end{bmatrix}$$

with all matrices fully written out including numerical values where possible. That is, your final answer should look something like:

$$\begin{bmatrix} 3 & 0 & 0 \\ 1 & 2 & -1 \\ 0 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} \Delta Q_1 \\ \Delta Q_2 \\ \Delta H_1 \end{bmatrix} = \begin{bmatrix} 21.3 \\ -9.6 \\ -0.53 \end{bmatrix}$$

Note that you are "hitting the reset button" on finding the solutions, so you should not be using the solutions for flows and heads you found in Problem 1 in this problem. However, you may calculated values for other parameters from your work on Problem 1. You must explicitly state all assumptions made in this problem.

(30 points)

The unit conversion coefficient in the Hazen-Williams Equation

After reviewing the textbook material on the Hazen-Williams Equation (H-W), we've realized that some of the values given for the unit conversion coefficient C_u do not agree with the units given for them. I have verified all of the information below.

In its fundamental form, the H-W equation is (Liou 1998):

$$V = 0.849\, C\, R_h^{0.63}\, S^{0.54}$$

where V is pipe flow velocity (m/s), C is the H-W roughness value, R_h is hydraulic radius (m), and S is slope of the energy grade line (= H_f / L). Hydraulic radius is defined as the ratio of flow cross-sectional area to wetted perimeter, which is equal to D/4 for a circular pipe flowing full. Replacing V with Q/A, and implementing the other substitutions listed above:

$$Q = 0.278\, C\, D^{2.63} \left(\frac{H_f}{L} \right)^{0.54}$$

for [Q] = m^3/s, [D] = m, [H_f] = m, and [L] = m. The value 0.278 is commonly noted as C_u, the unit conversion coefficient. The appropriate value of C_u can be determined for any combination of units using the following:

$$C_u = \frac{\left(\dfrac{Q\ units}{m^3/s} \right) \cdot \left(\dfrac{L\ units}{m} \right)^{0.54}}{\left(\dfrac{D\ units}{m} \right)^{2.63} \cdot \left(\dfrac{H_f\ units}{m} \right)^{0.54}} \quad \times \quad 0.278$$

where *Q units* is the unit conversion factor from m^3/s to the desired system (e.g., to use gallons per minute, $\left(\dfrac{Q\ units}{m^3/s} \right) = 15850$), etc.

The table below gives C_u values for some common unit choices.

Flow units	Diameter units	Head Loss units	Pipe Length units	C_u
m^3/s	m	m	m	0.278
gal/min	in	ft	ft	0.281
gal/sec	in	ft	ft	0.00468
MGD	ft	ft	ft	0.279
gal/min	ft	ft	ft	194
gal/day	in	ft	ft	405
ft^3/sec	in	ft	ft	0.000626
ft^3/sec	ft	ft	ft	0.431

Lamont found that it was not possible to develop a single correlation between pipe age and C-factor and that, instead, the decrease in C-factor also depended heavily on the corrosiveness of the water being carried. He developed four separate "trends" in carrying capacity loss depending on the "attack" of the water on the pipe. Trend 1, slight attack, corresponded to water that was only mildly corrosive. Trend 4, severe attack, corresponded to water that would rapidly attack cast iron pipe. As can be seen from Table 2.3, the extent of attack can significantly affect the C-factor. Testing pipes to determine the loss of carrying capacity is discussed further on page 196.

Table 2.3 C-factors for various pipe materials

	C-factor Values for Discrete Pipe Diameters					
Type of Pipe	1.0 in. (2.5 cm)	3.0 in. (7.6 cm)	6.0 in. (15.2 cm)	12 in. (30 cm)	24 in. (61 cm)	48 in. (122 cm)
Uncoated cast iron - smooth and new		121	125	130	132	134
Coated cast iron - smooth and new		129	133	138	140	141
30 years old						
Trend 1 - slight attack		100	106	112	117	120
Trend 2 - moderate attack		83	90	97	102	107
Trend 3 - appreciable attack		59	70	78	83	89
Trend 4 - severe attack		41	50	58	66	73
60 years old						
Trend 1 - slight attack		90	97	102	107	112
Trend 2 - moderate attack		69	79	85	92	96
Trend 3 - appreciable attack		49	58	66	72	78
Trend 4 - severe attack		30	39	48	56	62
100 years old						
Trend 1 - slight attack		81	89	95	100	104
Trend 2 - moderate attack		61	70	78	83	89
Trend 3 - appreciable attack		40	49	57	64	71
Trend 4 - severe attack		21	30	39	46	54
Miscellaneous						
Newly scraped mains		109	116	121	125	127
Newly brushed mains		97	104	108	112	115
Coated spun iron - smooth and new		137	142	145	148	148
Old - take as coated cast iron of same age						
Galvanized iron - smooth and new	120	129	133			
Wrought iron - smooth and new	129	137	142			
Coated steel - smooth and new	129	137	142	145	148	148
Uncoated steel - smooth and new	134	142	145	147	150	150

From Haestad Methods, et al. (2003)

Table 2.3 (cont.) C-factors for various pipe materials

Type of Pipe	C-factor Values for Discrete Pipe Diameters					
	1.0 in. (2.5 cm)	3.0 in. (7.6 cm)	6.0 in. (15.2 cm)	12 in. (30 cm)	24 in. (61 cm)	48 in. (122 cm)
Coated asbestos cement - clean		147	149	150	152	
Uncoated asbestos cement - clean		142	145	147	150	
Spun cement-lined and spun bitumen- lined - clean		147	149	150	152	153
Smooth pipe (including lead, brass, copper, polyethylene, and PVC) - clean	140	147	149	150	152	153
PVC wavy - clean	134	142	145	147	150	150
Concrete - Scobey						
Class 1 - Cs = 0.27; clean		69	79	84	90	95
Class 2 - Cs = 0.31; clean		95	102	106	110	113
Class 3 - Cs = 0.345; clean		109	116	121	125	127
Class 4 - Cs = 0.37; clean		121	125	130	132	134
Best - Cs = 0.40; clean		129	133	138	140	141
Tate relined pipes - clean		109	116	121	125	127
Prestressed concrete pipes - clean				147	150	150

Lamont (1981)

From a purely theoretical standpoint, the C-factor of a pipe should vary with the flow velocity under turbulent conditions. Equation 2.22 can be used to adjust the C-factor for different velocities, but the effects of this correction are usually minimal. A two-fold increase in the flow velocity correlates to an apparent five percent decrease in the roughness factor. This difference is usually within the error range for the roughness estimate in the first place, so most engineers assume the C-factor remains constant regardless of flow (Walski, 1984). However, if C-factor tests are done at very high velocities (i.e., >10 ft/s), then a significant error can result when the resulting C-factors are used to predict head loss at low velocities.

$$C = C_o\left(\frac{V_o}{V}\right)^{0.081} \qquad (2.22)$$

where C = velocity adjusted C-factor
C_o = reference C-factor
V_o = reference value of velocity at which C_0 was determined (L/T)

Manning Equation

Another head loss expression more typically associated with open channel flow is the *Manning equation*:

From EPANet Manual (Rossman 2000), with editing:

Table 3.2 Roughness Coefficients for New Pipe

Material		*Darcy-Weisbach ε (feet x 10^{-3})*	
Cast Iron		0.85	
Concrete or Concrete Lined		1.0 - 10	
Galvanized Iron		0.5	
Plastic		0.005	
Steel		0.15	
Vitrified Clay			

Swamee-Jain Equation:

$$f = \frac{0.25}{\left[\ln\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2}$$

Properties of water:

μ = 2.09 × 10^{-5} lb·sec/ft^2

ρ = 1.94 slugs/ft^3