CEE 371	October 8, 2009

Exam #1

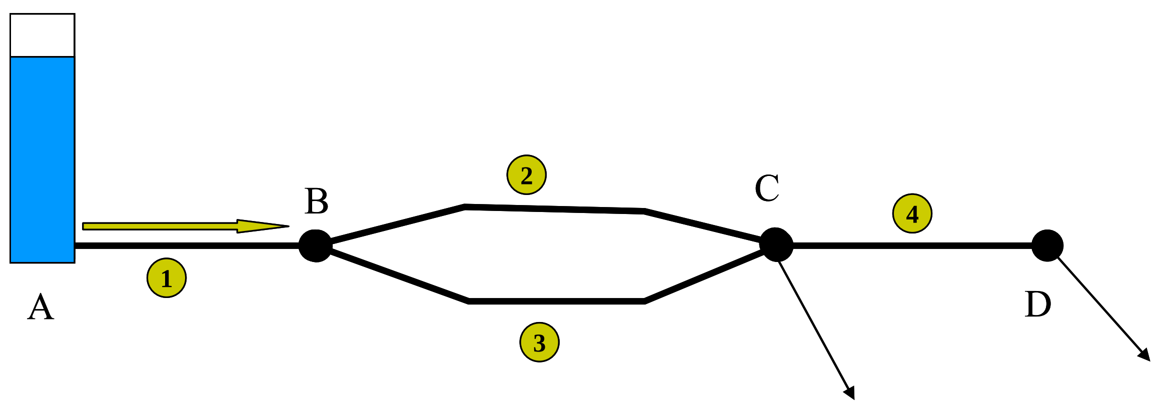
Closed Book, one sheet of notes allowed
Please answer one question from the first two, one from the second two and one from the last three. The total potential number of points is 100. Show all work. Be neat, and box-in your answer.

Please grade the following questions:
1 or 2
3 or 4
5, 6 or 7
Circle one from each row

A. Answer any 1 of the following 2 questions

1. Basic Hydraulics (40 points)

As shown in the schematic below, water can flow from the storage tank through the pipes to satisfy the demands at nodes C & D. Relevant data for the system are shown in the table below. <u>Calculate results for all missing values in the table</u>. Explain and show all work, and assume a Hazen Williams "C" value of 100 for all pipes.



PIPES					NODES				
No.	Length (ft)	Diam (in)	Flow (gpm)	h_f (ft)	No.	Elev. (ft)	HGL (ft)	Pressure (psi)	Demand (gpm)
1	4000	18			A	450	560		0
2	1000	12			B	320			0
3	1200	10		14	C	380			750
4	2500	14			D	350			

Q in gpm; D in inches

use Hazen - Williams equation

$$Q = 0.281 C D^{2.63} \left(\frac{h_f}{L} \right)^{0.54}$$

<u>Step #</u>

1 calculate flow for pipe #3

2 note that headloss for pipe #2 must be the same as for pipe #3 (they are parallel pipes)

3 calculate flow for pipe #2

4 flow in pipe #1 is sum of flows for #2 and #3

5 flow in pipe #4 is equal to #1 minus demand at node C

6 demand at node D must be equal to flow in pipe #4

7 calculate headloss in pipe #1

8 calculate headloss in pipe #4

$$h_L = 10.5\frac{Q^{1.85}L}{C^{1.85}D^{4.87}}$$

use HGL and Bernoulli Equation

Step #

9 calculate pressure at node A

10 determine HGL value for node B

11 determine HGL value for node C

12 determine HGL value for node D

13 calculate pressure at node B

14 calculate pressure at node C

15 calculate pressure at node D

$$HGL_2 = HGL_1 - h_{L_{1-2}}$$

$$HGL = Z + \frac{P}{\gamma}$$

Answers in Red below

PIPES					NODES				
No.	Length (ft)	Diam (in)	Flow (gpm)	h_f (ft)	No.	Elev. (ft)	HGL (ft)	Pressure (psi)	Demand (gpm)
1	4000	18	3014.93	17.65	A	450	560	47.67	0
2	1000	12	1931.36	14	B	320	542.35	96.35	0
3	1200	10	1083.57	14	C	380	528.35	64.29	750
4	2500	14	2264.93	22.10	D	350	506.25	67.71	2264.93

2. *Water Distribution Pipe Systems (40 points)*

a. For the pipe system shown below (Figure 1; including pipes #1-#4), determine the length of a single equivalent pipe that has a diameter of 12 inches. Use the Hazen Williams equation and assume that C_{HW} = 120 for all pipes. Start by assuming a flow of 1200 gpm in pipe #2. Please show all steps.

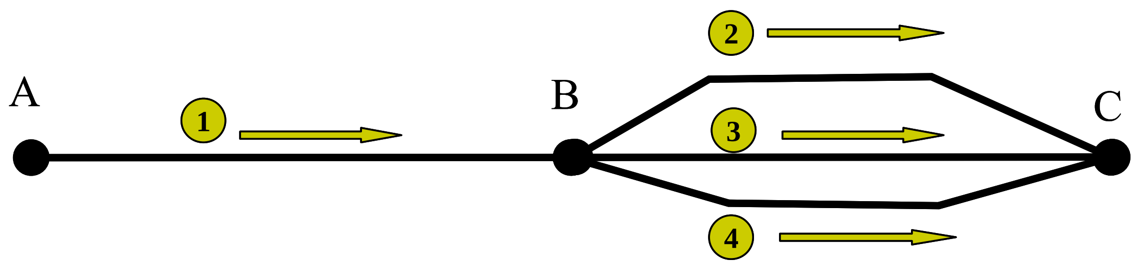


Figure 1. Pipe System for equivalent pipe problem

Table 1. Pipe Data for Figure 1 Pipe System

	Pipe 1	Pipe 2	Pipe 3	Pipe 4	
Length	900	1100	800	1000	ft
Diameter	16	10	8	10	in

<u>Steps</u>

1. Determine headloss in pipe #2; which is the node B-C headloss

$$\begin{aligned} h_L &= 10.5\frac{Q^{1.85}L}{C^{1.85}D^{4.87}} \\ &= 10.5\frac{(1200)^{1.85}1100}{(120)^{1.85}(10)^{4.87}} \\ &= 11.03\,ft \end{aligned}$$

2. Establish flow for pipe 3 and 4 based on the node B-C headloss.

   For pipe #3

$$\begin{aligned} Q &= 0.281\frac{h_L^{0.54}CD^{2.63}}{L^{0.54}} \\ &= 792.2gpm \end{aligned}$$

   For pipe #4

$$\begin{aligned} Q &= 0.281\frac{h_L^{0.54}CD^{2.63}}{L^{0.54}} \\ &= 1263.4gpm \end{aligned}$$

3. Determine the total flow from node B to C

   Q = 1200 + 792.2 + 1263.4 = 3256 gpm

   While not necessary for this problem, you may calculate the length of 12 inch pipe that is equivalent to pipes 2, 3 and 4. The correct length would be 421 ft.

4. Calculate headloss in pipe 1 based on the recognition it must carry the total flow for pipes 2-4

$$
\begin{aligned}
h_L &= 10.5\frac{Q^{1.85}L}{C^{1.85}D^{4.87}} \\
&= 5.80\,ft
\end{aligned}
$$

5. Determine the overall headloss by adding the headloss for node A-B and B-C

$$h_L = 5.80 + 11.03 = 16.83 \text{ ft}$$

6. Back calculate a 12" pipe length that has that headloss at the total system flow.

$$
\begin{aligned}
L &= \frac{h_L C^{1.85} D^{4.87}}{10.5Q^{1.85}} \\
&= \frac{16.83(120)^{1.85}(12)^{4.87}}{10.5(3256)^{1.85}} \\
&\boxed{= 644\,ft}
\end{aligned}
$$

B. Answer any 1 of the following 2 questions

3. Population and Water Use (40 points)

Table 1 contains population data for Hadley MA. In 2000, Hadley provided an average of 0.28 MGD to its customers. At that time 55% of the Hadley population was on city water.

Table 1. Population for Hadley, MA, 1930 -2000

Year	Population
1930	2682
1940	2576
1950	2639
1960	3099
1970	3760
1980	4125
1990	4231
2000	4793

a. Using this historical population, make population projections for 2015 and 2030 for Hadley. Use two different mathematical models of your choice. Discuss the pros and cons of the two models you selected. Clearly explain your approach and state all assumptions.

b. Using your population projections from part "a", estimate the average daily and maximum daily demands (in MGD) for 2015 and 2030.

c. Calculate the fire demand needed for Hadley for 2030 using your population projections from part “a”. Express answers in units of gpm and MGD.

Solution:

First you need a strategy to calculate average demand based on predicted population. One valid approach is to assume the per capita average demand will remain constant (i.e., apply the value you have for 2000; taking into account that 55% of the population is using the city water). This is preferable to use of a “national average” value such as 180 gpcd. Next you need to decide if the percent on city water will remain at 55% or if it will change (if it does change, it’s likely to go up). Finally, then you need a strategy to calculate maximum day demand. A valid approach here would be to use the 1.8 ratio as done in class. Finally you need the fire flow equation. While not perfect for this example, it is a reasonable way of estimating fire flows in the absence of other data

Per capita usage specific to Hadley based on 2000 data:

$$usage = \frac{280{,}000 gal}{4{,}793\ people(0.55)} = 106.2\ gpcd$$

Max day demand requires use of a national average (e.g., 1.8 x avg demand), since we don’t have any Hadley-specific data

Fire flow can be determined from the standard equation:

$$Q = 1020\left(\sqrt{P}\right)\left(1 - 0.01\sqrt{P}\right)$$

I then Set t_0 = 1930, and proceeded as follows for each model:

1. calibrate models (evaluating coefficients)
2. apply models to predict population in 2015 and 2030
3. calculate average demand, maximum demand and fire flow for each prediction

applying and calibrating the models requires that you decide which data to use. There are many valid ways of doing this:

- select al data and do a least squares linear regression (this is what I’ve done below)
- inspect the data and select two or more data points that seem to represent current trends; them may be the last two data points, or possible some from the late 1900s. I would not, however just select the first and last data point.

Below I show calculations and graphs for 4 different models. You only needed to do the calculations for two of these.

There are many ways of calibrating your model. The simplest is to select 2 dates and use only those population data. While easy, this method does not take fullest advantage of the complete data set. A more powerful approach is to use a least squares linear regression of the linearized data.

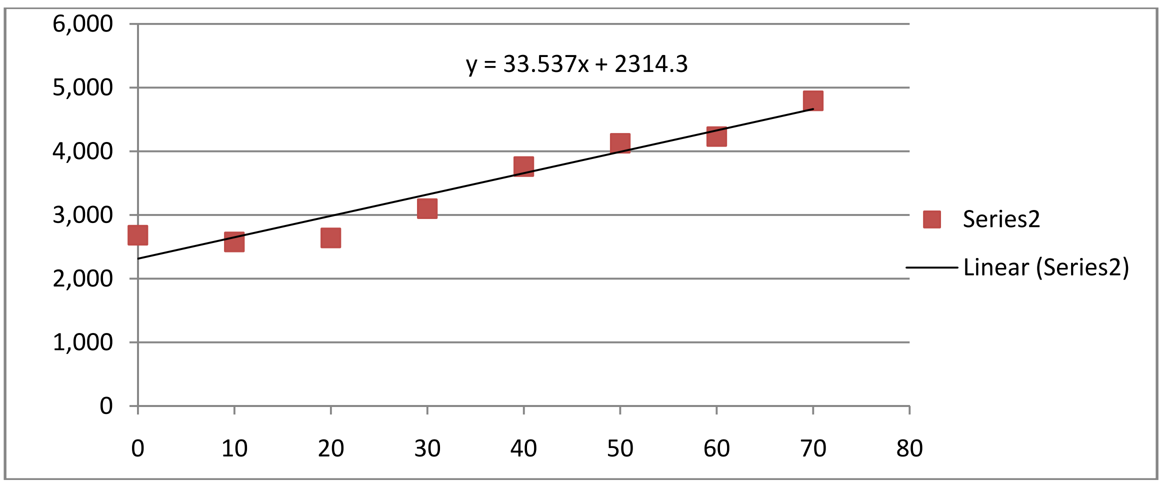
$$Y = Y_o + K_a(t - t_o) \quad (1c)$$

Linear Model							
				Demand (MGD)		Fire Flow	
	t-t0	Year	Population	Avg	Max	(gpm)	(MGD)
	0	1930	2,682				
	10	1940	2576				
	20	1950	2639				
	30	1960	3099				
	40	1970	3760				
	50	1980	4125				
	60	1990	4231				
	70	2000	4793	0.28			
	85	2015	5,165	0.30	0.54	2,265	3.26
	100	2030	5,668	0.33	0.60	2,371	3.42
		Yo =	2314.3				
		Ka=	33.537				

$$Y = Y_o + K_a(t - t_o) \quad (1c)$$

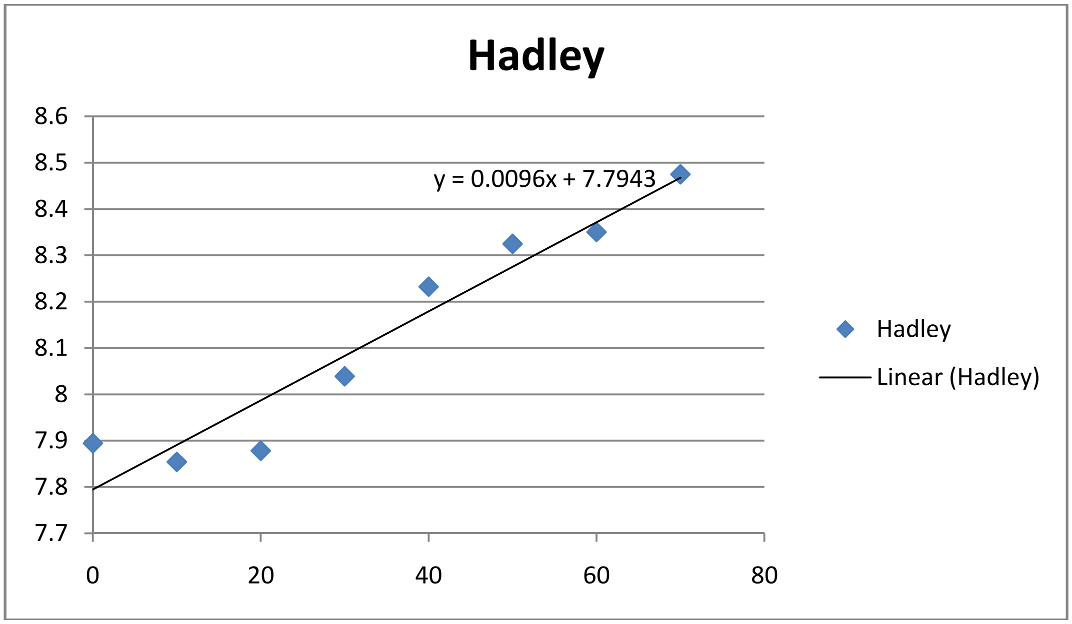
$$Q = 1020\left(\sqrt{P}\right)\left(1 - 0.01\sqrt{P}\right)$$

Using all of the data gets you a Ka of 33.54



Exponential Model									
				Demand (MGD)		Fire Flow			
	t-t0	Year	Population	Avg	Max	(gpm)	(MGD)		ln(pop)
	0	1930	2682						7.8943181
	10	1940	2576						7.8539931
	20	1950	2639						7.8781553
	30	1960	3099						8.0388348
	40	1970	3760						8.2321742
	50	1980	4125						8.3248213
	60	1990	4231						8.3501937
	70	2000	4793	0.28					8.4749118
	85	2015	5,488	0.32	0.58	2,334	3.36		8.6103
	100	2030	6,338	0.37	0.67	2,503	3.61		8.7543
								LnYo =	7.7943
								Ke=	0.0096

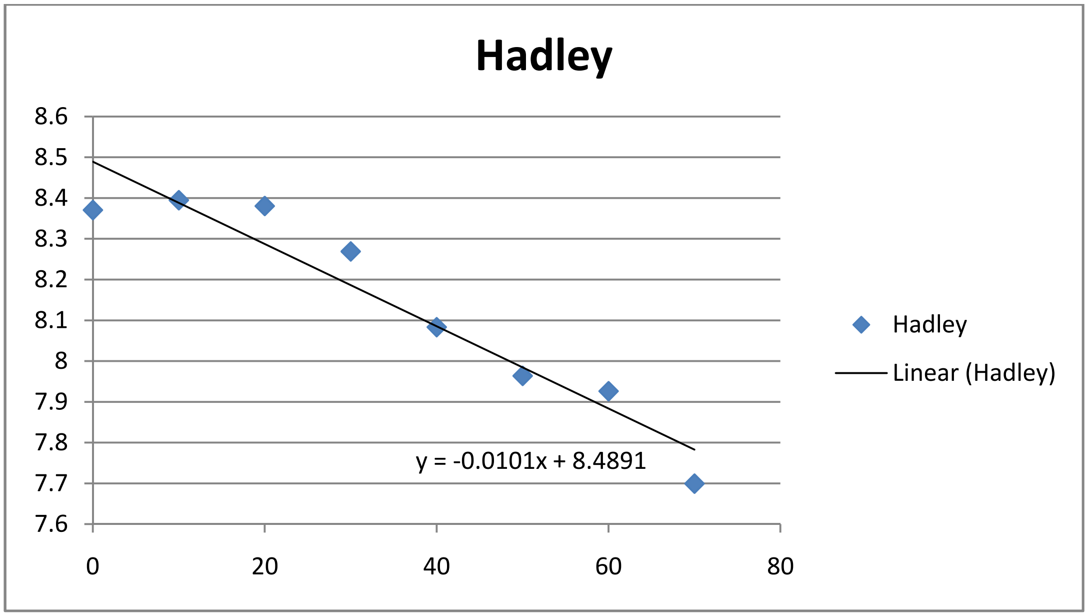
$$\ln Y = \ln Y_o + K_e\,(t - t_o) \quad (2c)$$



Declining Growth Model								z =	7,000
				Demand (MGD)		**Fire Flow**			
	t-t0	**Year**	**Pop = Y**	**Avg**	**Max**	**(gpm)**	**(MGD)**		**ln(Z-Y)**
	0	1930	2682						8.3705476
	10	1940	2576						8.3947995
	20	1950	2639						8.3804567
	30	1960	3099						8.2689882
	40	1970	3760						8.0833286
	50	1980	4125						7.963808
	60	1990	4231						7.9262415
	70	2000	4793	0.28					7.6993894
	85	2015	4,938	0.29	0.52	2,216	3.19		7.6314
	100	2030	5,228	0.31	0.55	2,279	3.28		7.4800
								Ln(Z-Yo) =	8.4891326
								Kd=	-0.0100911

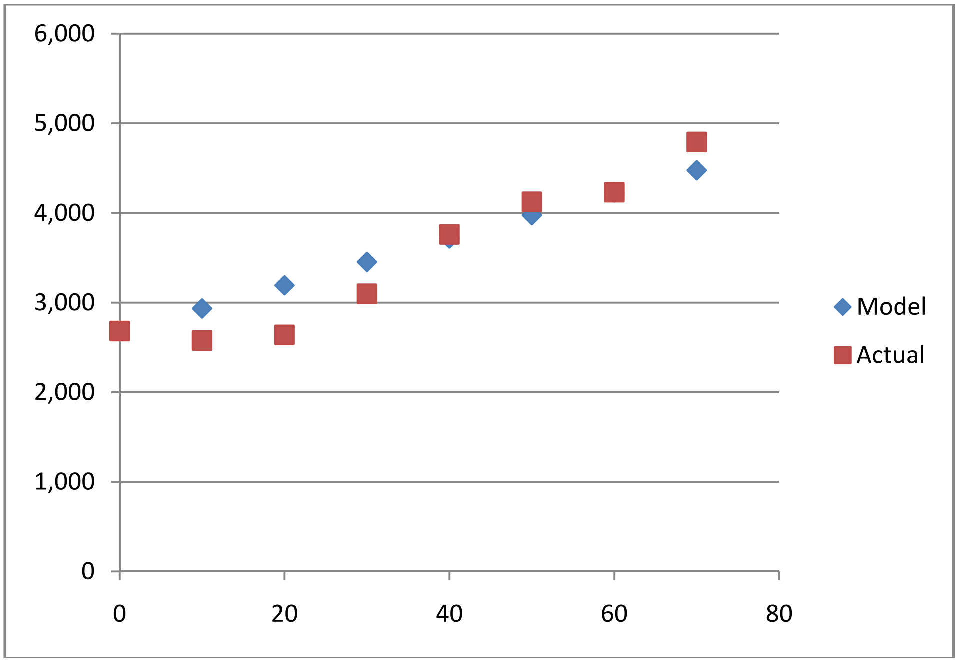
$$Y = Y_o + (Z - Y_o)(1 - e^{-K_d(t - t_o)}) \quad (3d)$$

$$\ln(Z - Y) = \ln(Z - Y_0) - K_d t \quad (3b)$$



Logistics Model										
				Demand (MGD)		Fire Flow				
	t-t0	Year	Pop = Y	Avg	Max	(gpm)	(MGD)		logistics	% error
	0	1930	2682						2,682	0%
	10	1940	2576						2,934	14%
	20	1950	2639						3,192	21%
	30	1960	3099						3,454	11%
	40	1970	3760						3,716	-1%
	50	1980	4125						3,976	-4%
	60	1990	4231						4,231	0%
	70	2000	4793	0.28					4,477	-7%
	85	2015	4,828	0.28	0.51	2,192	3.16		4,828	
	100	2030	5,150	0.30	0.54	2,262	3.26		5,150	
								K =	7,000	pop
								r =	0.015	yr-1
								No =	2,682	pop

$$N_t = \frac{K}{1 + \left[\left(\frac{K - N_0}{N_0}\right)e^{-rt}\right]} = \frac{KN_o}{N_o + (K - N_o)e^{-rt}}$$



4. *Water Distribution System Storage (40 points)*

a. Given the hourly average demand rates shown below (in gpm), calculate the uniform 24 hour supply (or pumping) rate and the required equalizing storage volume (in million gallons). Prepare a cumulative demand graph for the problem. Find the equalizing storage using the cumulative demand graph.

b. Make an estimate of the total required distribution storage volume for this community. Assume that the information for part "a" is for the average day flow for a community of 20,000 people and that the ratio of Q max day to Q average day is 1.8 for this community. Also assume that this community has a backup supply it can use in emergencies. For design purposes assume a fire duration of 10 hours. Clearly state any additional assumptions you make.

12 midnight	1000
1 AM	950
2	900
3	875
4	850
5	900
6	1840
7	4100
8	3850
9	2850
10	2200
11	3050

12 noon	3150
1 PM	3250
2	2830
3	2732
4	3050
5	3350
6	3515
7	4500
8	4345
9	2610
10	1100
11	1050
12 midnight	1000

Answer:

Preliminary calculation for demand graphs:

			24 hr supply	24 hr supply
	TIME	DEMAND (GPM)	Cumulative Demand (gal)	Cumulative Supply (gal)
midnight	12	1000	0	0
a.m.	1	950	58500	147118
	2	900	114000	294235
	3	875	167250	441353
	4	850	219000	588470
	5	900	271500	735588
	6	1840	353700	882705
	7	4100	531900	1029823
	8	3850	770400	1176940
	9	2850	971400	1324058
	10	2200	1122900	1471175
	11	3050	1280400	1618293
noon	12	3150	1466400	1765410
	1	3250	1658400	1912528
p.m.	2	2830	1840800	2059645
	3	2732	2007660	2206763
	4	3050	2181120	2353880
	5	3350	2373120	2500998
	6	3515	2579070	2648115
	7	4500	2819520	2795233
	8	4345	3084870	2942350
	9	2610	3293520	3089468
	10	1100	3404820	3236585
	11	1050	3469320	3383703
	12	1000	3530820	3530820
Avg Q		2452		

Cumulative flow graph for calculating Equalizing Storage

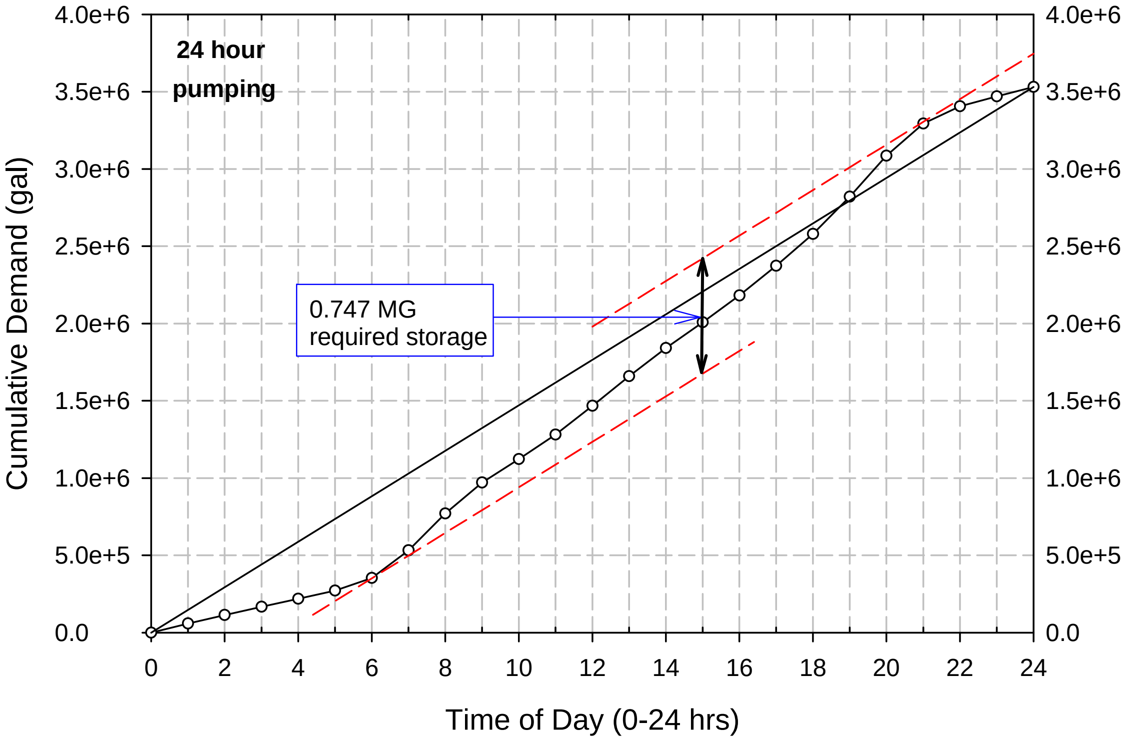


Figure 2. Cumulative Demand

Figure 2. Cumulative Demand with 24 Hour Pumping

Assumption: use 24 hr pumping; multiple sources so that emergency storage isn't needed.

Fire Flow

$$
\begin{aligned}
Q_{fire} &= 1020\left(\sqrt{P}\right)\left(1-0.01\sqrt{P}\right) \\
&= 1020\left(\sqrt{20}\right)\left(1-0.01\sqrt{20}\right) \\
&= 4358\,gpm \\
&= 6.27\,MGD
\end{aligned}
$$

V_{fire} = Duration * Q_{fire} = (10/24) days * 6.27 MGD = **2.61 MG**

Equalizing storage based on average daily flow (determined in part 1), must be adjusted for max daily flow

Q_{equal} =1.8 x 0.75 MG = **1.34 MG**

Total Required Storage

Q_{tot} = 2.61 + 1.34 = **3.95 MG**

C. Answer one of the following 3 questions

5. Cost Estimation (20 points)

Bids for construction of the new 7500 ft long transmission main are taken and a young CEE 371 engineer informs Oakdale's experienced Director of Public Works that the low bidder's cost is $720,000. The Director is clearly unhappy and says, "They must be nuts! Just a short while back in 1970 (ENRCCI = 1381) in Milltown (a neighboring community) we installed 2.5 miles of that same size pipe for only $220,000" The engineer replies, "I think they have given a fair price." Who do you agree with? Support your answer quantitatively and state assumptions (Sept 2009 ENRCCI = 8586).

Solution:

The engineer is correct. The new bid price is a bit better than the 1970 price, accounting for the differences in length and increases in the CCI.

				length		cost per ft	
Year	CCI		Bid	ft	mi	as bid	2009 dollars
1970	1381		$ 220,000	13200	2.5	$ 16.67	$ 103.62
2009	8586		$ 720,000	7500		$ 96.00	$ 96.00

6. Multiple Choice. Circle the answer that is most correct. (20 points total; 2.5 points each)

a. A typical design period for a water transmission main is

1. **1 year**
2. **5 years**
3. **25 years**
4. **50 years**
5. **300 years**

b. A town has a present population of 45,000 people and has grown by 10,000 people over the last 20 years. If you use an exponential model for growth, what population would you predict for 20 years into the future?

1. **47,982**
2. **55,000**
3. **57,857**
4. **65,441**
5. **none of the above**

Note that K_e = 0.012566 yr-1
Which gives y=57,857.14
For 20 years in the future

c. For question b, what would the population be if you assume linear growth?

1. **47,982**
2. **55,000**
3. **57,857**

4. 65,441
5. none of the above

d. A community has a population of 37,500. What fire demand would you design for in MGD?

1. 5.9 MGD
2. 62.8 MGD
3. 0.6 MGD
4. 43,600 MGD
5. none of the above

e. The average daily demand for the community per question d is 7.3 MGD. Their average daily per capita demand is about

1. 195 gpcd
2. 175 gpcd
3. 155 gpcd
4. 135 gpcd
5. none of the above

f. A good estimate of the maximum daily demand for the community in questions d and e is.

1. 5 MGD
2. 18 MGD
3. 21 MGD
4. 29 MGD
5. none of the above

g. Drinking water distribution systems

1. Are best designed as grids with many loops
2. Must provide adequate water storage within the pipes themselves
3. Should be constructed based on the average daily demand
4. Should provide pressures of at least 150 psi
5. All of the above
6. None of the above

h. Connecting identical pumps in series

1. Results in a higher shutoff head downstream of the pumps than if they were in parallel
2. Results in a higher flow rate at normal operating heads, than if they were in parallel
3. Is always the most economical solution
4. Is never done because of high maintenance costs
5. All of the above
6. None of the above

7. Power (20 points)

Water is pumped 7 miles from a reservoir at an elevation of 290 ft to a second reservoir at an elevation of 880 ft. The pipeline connecting the reservoirs is 36 inches in diameter. It is concrete with a C of 100, the flow is 20 MGD, and the pump efficiency is 82%. What is the monthly power bill if electricity costs 10 cents per kilowatt-hour? (ignore minor losses)

Solution:

Use the Hazen-Williams and power equations:

$$h_L = 10.6\frac{Q^{1.85}L}{C^{1.85}D^{4.87}}$$

Where Q is in MGD, and D is in feet

Then use the Bernoulli equation:

$$\frac{P_1}{\gamma} + \frac{v_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + Z_2 + h_{L1\to 2}$$

Recognizing that velocity drops out, and that the pressure in an open reservoir is zero, this becomes

$$h_T = \frac{P_1}{\gamma} = Z_2 - Z_1 + h_{L1\to 2}$$

power equation:

$$P = \frac{Q\gamma h_T}{\eta} = \frac{20MDG\left(62.4\,{}^{lb}\!/\!_{ft^3}\right)684.7\,ft}{0.82}1.54\frac{ft^3}{MGD}1.3558\frac{watts}{ft-lb/s} = 2.186x10^6\,watts$$

And finally the results:

1	calculate headloss					
		hL =	94.703	ft =	28.86541	m
2	Calculate the total head					
		hT =	684.703	ft =	208.6974	m
3	calculate power					
		P =	2185507.81	watts =	2185.508	KW
4	cost					
		Energy =	1596513.46	KW-H/month		
		Cost =	$ 159,651	per month		

Good stuff to know

Conversions

7.48 gallon = 1.0 ft^3 1 gal = 3.7854×10^{-3} m^3

1 MGD = 694 gal/min = 1.547 ft^3/s = 43.8 L/s

1 ft^3/s = 449 gal/min

g = 32 ft/s^2

W=γ = 62.4 lb/ft^3 = 9.8 N/L

1 hp = 550 ft-lbs/s = 0.75 kW

1 mile = 5280 feet 1 ft = 0.3048 m

1 watt = 1 N-m/s

1 psi pressure = 2.3 vertical feet of water (head)

At 60 ºF, $\nu = 1.217 \times 10^{-5}$ ft^2/s

HGL = $Z + P/\gamma$ EGL = $V^2/2g + Z + P/\gamma$

$[V^2/2g + Z + P/\gamma]_1 + H_{pump} = [V^2/2g + Z + P/\gamma]_2 + H_{L\ 1\text{-}2}$

Hazen-Williams equation (circular pipe)

Q in cfs, V in ft/s, D in ft:

$Q = 0.432\ C\ D^{2.63}\ S^{0.54}$ $S = h_f/L = 4.73\ (Q^{1.85})/(C^{1.85}\ D^{4.87})$

Q in gpm, D in inches:

$Q = 0.281\ C\ D^{2.63}\ S^{0.54}$ $S = h_f/L = 10.5\ (Q^{1.85})/(C^{1.85}\ D^{4.87})$

Darcy-Weisbach equation:

$h_f = f\ (L/D)\ (V^2/2g)$ $Q = (g\ \pi^2/8)^{0.5}\ f^{-0.5}\ D^{2.5}\ S^{0.5}$

$Re = V\ D/\nu$

Pump Power: $P = (\gamma\ Q\ H)/\eta$

Population Projection Models:

Linear: $dY/dt = K_a$ $Y = Y_o + K_a(t - t_o)$

Exponential: $dY/dt = K_e\ Y$ $K_e = \frac{\ln Y_2 - \ln Y_1}{t_2 - t_1}$ $\ln Y = \ln Y_0 + K_e(t - t_0)$

Decreasing Rate of Increase:

$$\frac{dY}{dt} = K_d\ (Z - Y) \qquad K_d = \frac{-\ln \frac{Z - Y_2}{Z - Y_1}}{t_2 - t_1} \qquad Y = Y_0 + (Z - Y_0)(1 - e^{-K_D(t - t_0)})$$

Fireflow (Q) based on population (P)

$Q = 1020\ P^{1/2}\ (1 - 0.01\ P^{1/2})$ (Q in gpm, P in 1000s)

PHYSICAL AND CHEMICAL CONSTANTS

Avogadro's number	$\mathcal{N} = 6.022 \times 10^{23}$ mol^{-1}
Elementary charge	$e = 1.602 \times 10^{-19}$ C
Gas constant	$R = 8.314$ J mol^{-1} K^{-1}
	$= 1.987$ cal mol^{-1} K^{-1}
	$= 0.08205$ L atm mol^{-1} K^{-1}
Planck's constant	$h = 6.626 \times 10^{-34}$ J s
Boltzmann's constant	$\mathbf{k} = 1.381 \times 10^{-23}$ J K^{-1}
Faraday's constant	$F = 9.649 \times 10^{4}$ C mol^{-1}
Speed of light	$c = 2.998 \times 10^{8}$ m s^{-1}
Vacuum permittivity	$\varepsilon_0 = 8.854 \times 10^{-12}$ J^{-1} C^2 m^{-1}
Earth's gravitation	$g = 9.806$ m s^{-2}

CONVERSION FACTORS

1 cal	= 4.184 joules (J)
1 eV/molecule	= 96.485 kJ mol^{-1}
	= 23.061 kcal mol^{-1}
1 wave number (cm^{-1})	= 1.1970×10^{-2} kJ mol^{-1}
1 erg	= 10^{-10} kJ
1 atm	= 1.01325×10^{5} Pa
1 Å	= 10^{-10} m
1 L	= 10^{-3} m^3

PROPERTIES OF WATER

T(°C)	ρ, Density (kg · m^{-3})	μ Viscosity (kg · m^{-1} · s^{-1})	σ, Surface Tension against Air (J · m^{-2})	ε Dielectric Constant (C · V^{-1} · m^{-1})	pK_w, Ionization Constant (mol^2 · L^{-2})
0	999.868	0.001787	0.0756	88.28	14.9435
5	999.992	0.001519	0.0749	86.3	14.7338
10	999.726	0.001307	0.07422	84.4	14.5346
15	999.125	0.001139	0.07349	82.5	14.3463
20	998.228	0.001002	0.07275	80.7	14.1669
25	997.069	0.0008904	0.07197	78.85	13.9965
30	995.671	0.0007975	0.07118	77.1	13.8330

SI PREFIXES

Multiplication Factor	Prefix	Symbol	Multiplication Factor	Prefix	Symbol
10^{12}	tera	T	10^{-2}	centi	c
10^{9}	giga	G	10^{-3}	milli	m
10^{6}	mega	M	10^{-6}	micro	μ
10^{3}	kilo	k	10^{-9}	nano	n
10^{2}	hecto	h	10^{-12}	pico	p
10^{1}	deka	da	10^{-15}	femto	f
10^{-1}	deci	d	10^{-18}	atto	a