| CEE 371 | March 10, 2009 |
|---|---|

# Exam #1

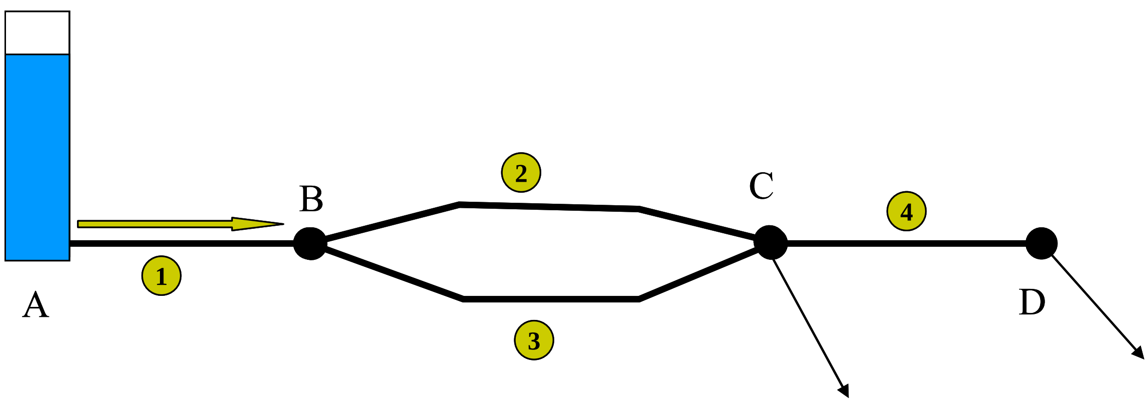
| Please grade the following questions: |
|---|
| 1 or 2 |
| 3 or 4 |
| 5, 6 or 7 |
| Circle one from each row |

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.

## 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. Calculate results for all missing values in the table. 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 | 5000 | 16 | | | A | 450 | 560 | | 0 |
| 2 | 800 | 10 | | | B | 320 | | | 0 |
| 3 | 1000 | 8 | | 14 | C | 380 | | | 500 |
| 4 | 2500 | 12 | | | D | 350 | | | |

**use Hazen - Williams equation**

Q in gpm; D in inches

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

Step #

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 | 5000 | 16 | 2013.68 | 18.56 | A | 450 | 560 | 47.67 | 0 |
| 2 | 800 | 10 | 1348.80 | 14 | B | 320 | 541.44 | 95.96 | 0 |
| 3 | 1000 | 8 | 664.88 | 14 | C | 380 | 527.44 | 63.89 | 500 |
| 4 | 2500 | 12 | 1513.68 | 22.21 | D | 350 | 505.23 | 67.27 | 1513.68 |

## 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 10 inches. Use the Hazen Williams equation and assume that $C_{HW}$ = 120 for all pipes. Start by assuming a flow of 1000 gpm in pipe #2. Please show all steps.

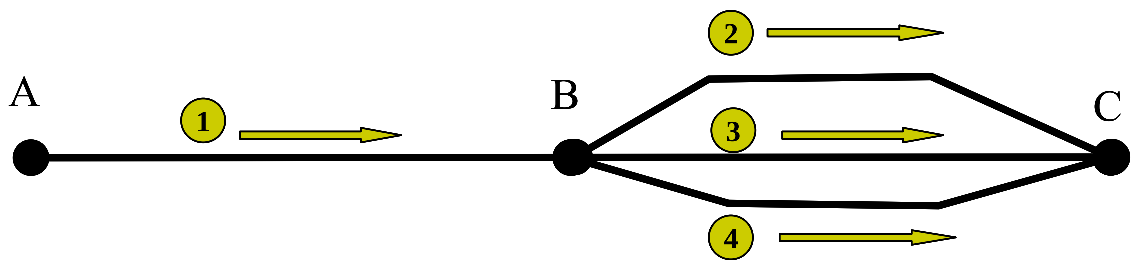



Figure 1. Pipe System for equivalent pipe problem

Table 1. Pipe Data for Figure 1 Pipe System

| | Pipe 1 | Pipe 2 | Pipe 3 | Pipe 4 | |
|---|---|---|---|---|---|
| Length | 900 | 1100 | 800 | 1000 | ft |
| Diameter | 12 | 10 | 8 | 10 | in |

Steps

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

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

$$= 10.5\frac{(1000)^{1.85}1100}{(120)^{1.85}(10)^{4.87}}$$

$$= 7.87\,ft$$

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

For pipe #3

$$Q = 0.281\frac{h_L^{0.54}CD^{2.63}}{L^{0.54}}$$

$$= 660.16gpm$$

For pipe #4

$$Q = 0.281\frac{h_L^{0.54}CD^{2.63}}{L^{0.54}}$$

$$= 1052.87gpm$$

3. Determine the total flow from node B to C

Q = 1000 + 660 + 1053 = 2713 gpm

While not necessary for this problem, you may calculate the length of 10 inch pipe that is equivalent to pipes 2, 3 and 4. The correct length would be 174 ft.

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

$$h_L = 10.5 \frac{Q^{1.85} L}{C^{1.85} D^{4.87}}$$
$$= 16.80\, ft$$

5. Determine the overall headloss by adding the headloss for node A-B and B-C
   $h_L = 7.87 + 16.80 = 24.67$ ft

6. Back calculate a 10" pipe length that has that headloss at the total system flow.

$$L = \frac{h_L C^{1.85} D^{4.87}}{10.5 Q^{1.85}}$$
$$= \frac{24.67(120)^{1.85}(10)^{4.87}}{10.5(2713)^{1.85}}$$
$$= 544\, ft$$

## B. Answer any 1 of the following 2 questions

### *3. Population and Water Use (40 points)*

Table 1 contains population data for Durham NC. In 2005, Durham's Division of Water Supply and Treatment provided an average of 27.65 MGD to its customers.

**Table 1. Population for Durham NC, 1890 -2005**

| Year | Population |
|---|---|
| 1890 | 5,485 |
| 1900 | 6,679 |
| 1910 | 18,241 |
| 1920 | 21,719 |
| 1930 | 52,037 |
| 1940 | 60,195 |
| 1950 | 73,368 |
| 1960 | 84,642 |
| 1970 | 100,768 |
| 1980 | 100,831 |
| 1990 | 136,611 |
| 2000 | 187,035 |
| 2005 | 208,816 |

a. Using this historical population, make population projections for 2015 and 2030 for Durham. 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 Durham 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 2005). This is preferable to use of a "national average" value such as 180 gpcd. 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 Durham based on 2005 data:

$$usage = \frac{27{,}650{,}000 gal}{208{,}514\ people} = 132.4\ gpcd$$

Max day demand requires use of a national average (e.g., 1.8 x avg demand), since we don't have any Durham-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 $t_0$ = 1890, 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 mid 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.

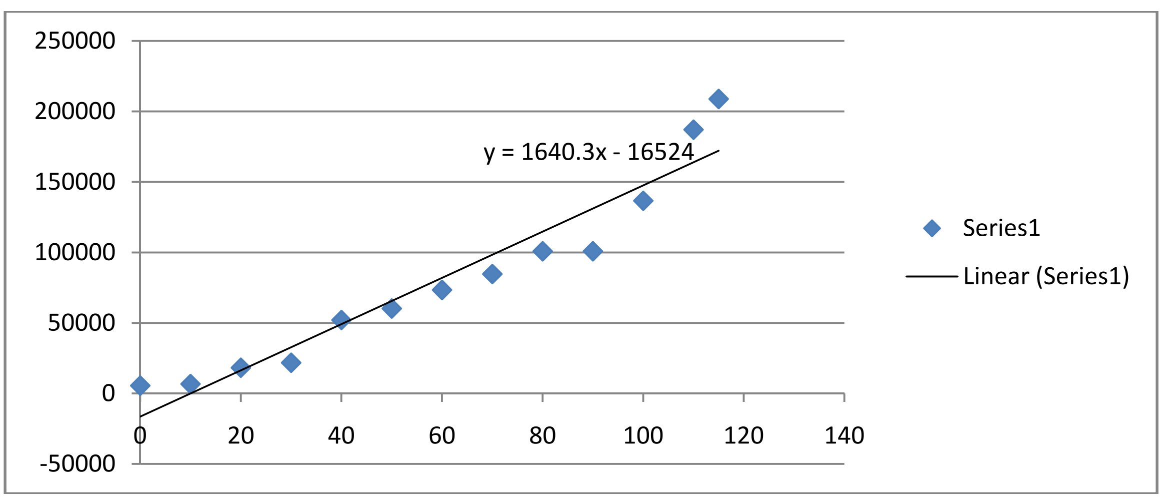
$$Y = Y_o + K_a(t - t_o) \quad (1c)$$

**Linear Model**

| | | | Demand (MGD) | | Fire Flow | |
|---|---|---|---|---|---|---|
| **t-t0** | **Year** | **Population** | **Avg** | **Max** | **(gpm)** | **(MGD)** |
| 0 | 1890 | 5,485 | | | | |
| 10 | 1900 | 6,679 | | | | |
| 20 | 1910 | 18,241 | | | | |
| 30 | 1920 | 21,719 | | | | |
| 40 | 1930 | 52,037 | | | | |
| 50 | 1940 | 60,195 | | | | |
| 60 | 1950 | 73,368 | | | | |
| 70 | 1960 | 84,642 | | | | |
| 80 | 1970 | 100,768 | | | | |
| 90 | 1980 | 100,831 | | | | |
| 100 | 1990 | 136,611 | | | | |
| 110 | 2000 | 187,035 | | | | |
| 115 | 2005 | 208,816 | 27.65 | | | |
| | | | | | | |
| 125 | 2015 | 188,514 | 24.96 | 44.93 | 12,082 | 17.41 |
| 140 | 2030 | 213,118 | 28.22 | 50.80 | 12,717 | 18.32 |

Yo = -16524
Ka= 1640.3

Using only the last two datapoints would get you a Ka of 4356

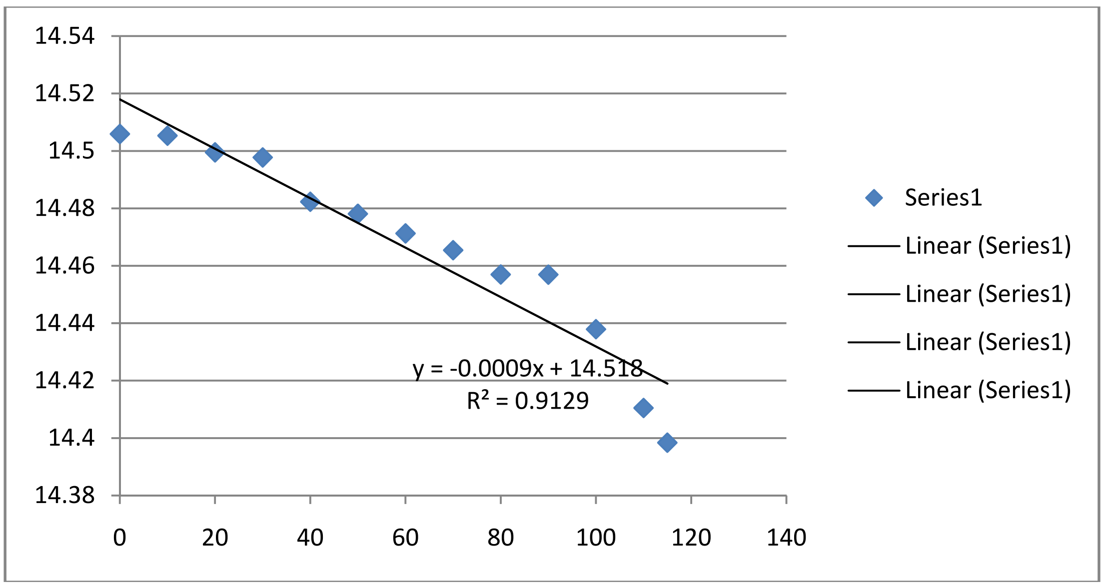


**Exponential Model**

| t-t0 | Year | Population | Demand (MGD) Avg | Max | Fire Flow (gpm) | (MGD) | ln(pop) |
|---|---|---|---|---|---|---|---|
| 0 | 1890 | 5,485 | | | | | 8.6097724 |
| 10 | 1900 | 6,679 | | | | | 8.8067236 |
| 20 | 1910 | 18,241 | | | | | 9.8114271 |
| 30 | 1920 | 21,719 | | | | | 9.9859427 |
| 40 | 1930 | 52,037 | | | | | 10.85971 |
| 50 | 1940 | 60,195 | | | | | 11.005345 |
| 60 | 1950 | 73,368 | | | | | 11.203243 |
| 70 | 1960 | 84,642 | | | | | 11.346186 |
| 80 | 1970 | 100,768 | | | | | 11.520576 |
| 90 | 1980 | 100,831 | | | | | 11.521201 |
| 100 | 1990 | 136,611 | | | | | 11.824893 |
| 110 | 2000 | 187,035 | | | | | 12.139051 |
| 115 | 2005 | 208,816 | 27.65 | | | | 12.249209 |
| 125 | 2015 | 352,992 | 46.74 | 84.13 | 15,563 | 22.43 | 12.7742 |
| 140 | 2030 | 550,290 | 72.87 | 131.16 | 18,314 | 26.39 | 13.2182 |

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

LnYo = 9.0742
Ke= 0.0296



## Declining Growth Model

z = 2,000,000

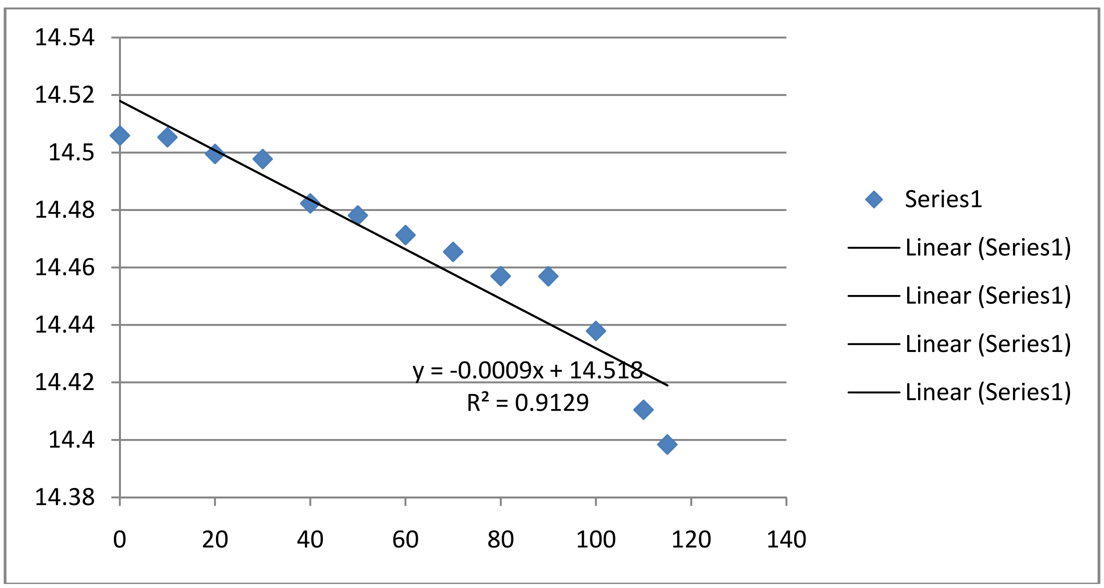
| t-t0 | Year | Pop = Y | Demand (MGD) Avg | Max | Fire Flow (gpm) | (MGD) | ln(Z-Y) |
|---|---|---|---|---|---|---|---|
| 0 | 1890 | 5,485 | | | | | 14.505911 |
| 10 | 1900 | 6,679 | | | | | 14.505313 |
| 20 | 1910 | 18,241 | | | | | 14.499495 |
| 30 | 1920 | 21,719 | | | | | 14.497739 |
| 40 | 1930 | 52,037 | | | | | 14.482295 |
| 50 | 1940 | 60,195 | | | | | 14.478098 |
| 60 | 1950 | 73,368 | | | | | 14.471284 |
| 70 | 1960 | 84,642 | | | | | 14.465415 |
| 80 | 1970 | 100,768 | | | | | 14.45696 |
| 90 | 1980 | 100,831 | | | | | 14.456927 |
| 100 | 1990 | 136,611 | | | | | 14.437907 |
| 110 | 2000 | 187,035 | | | | | 14.410474 |
| 115 | 2005 | 208,816 | 27.65 | | | | 14.398387 |
| | | | | | | | |
| 125 | 2015 | 187,288 | 24.80 | 44.64 | 12,049 | 17.36 | 14.4103 |
| 140 | 2030 | 210,548 | 27.88 | 50.18 | 12,653 | 18.23 | 14.3974 |

Ln(Z-Yo) = 14.51796

Kd= -0.000861

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

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

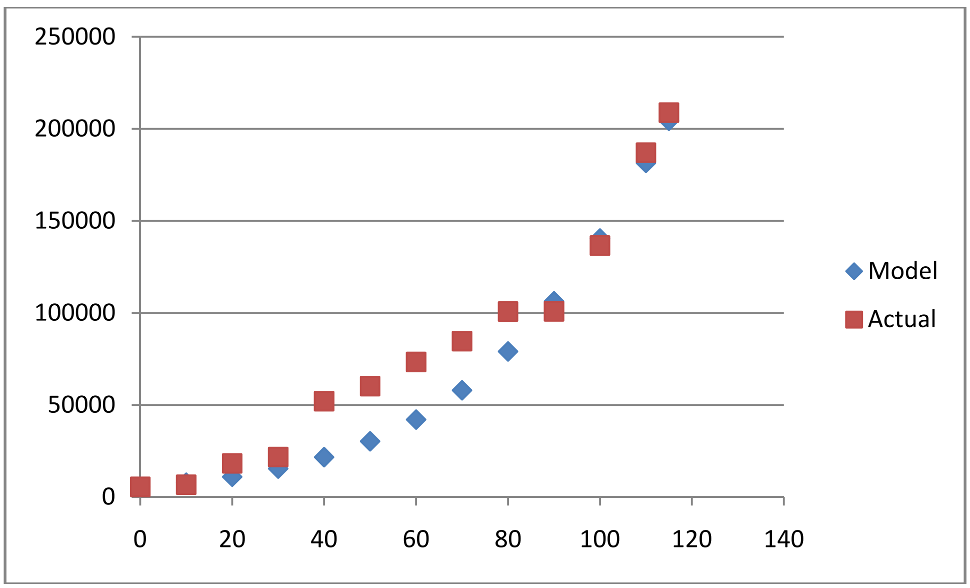


**Logistics Model**

| t-t0 | Year | Pop = Y | Demand (MGD) Avg | Max | Fire Flow (gpm) | (MGD) | logistics | % error |
|---|---|---|---|---|---|---|---|---|
| 0 | 1890 | 5,485 | | | | | 5,485 | 0% |
| 10 | 1900 | 6,679 | | | | | 7,754 | 16% |
| 20 | 1910 | 18,241 | | | | | 10,944 | -40% |
| 30 | 1920 | 21,719 | | | | | 15,412 | -29% |
| 40 | 1930 | 52,037 | | | | | 21,638 | -58% |
| 50 | 1940 | 60,195 | | | | | 30,249 | -50% |
| 60 | 1950 | 73,368 | | | | | 42,038 | -43% |
| 70 | 1960 | 84,642 | | | | | 57,953 | -32% |
| 80 | 1970 | 100,768 | | | | | 79,039 | -22% |
| 90 | 1980 | 100,831 | | | | | 106,294 | 5% |
| 100 | 1990 | 136,611 | | | | | 140,414 | 3% |
| 110 | 2000 | 187,035 | | | | | 181,461 | -3% |
| 115 | 2005 | 208,816 | 27.65 | | | | 204,346 | -2% |
| 125 | 2015 | 253,762 | 33.60 | 60.48 | 13,660 | 19.68 | 253,762 | |
| 140 | 2030 | 332,018 | 43.96 | 79.13 | 15,199 | 21.90 | 332,018 | |

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

| | | |
|---|---|---|
| K = | 600,000 | pop |
| r = | 0.035 | yr-1 |
| No = | 5,485 | pop |




## 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

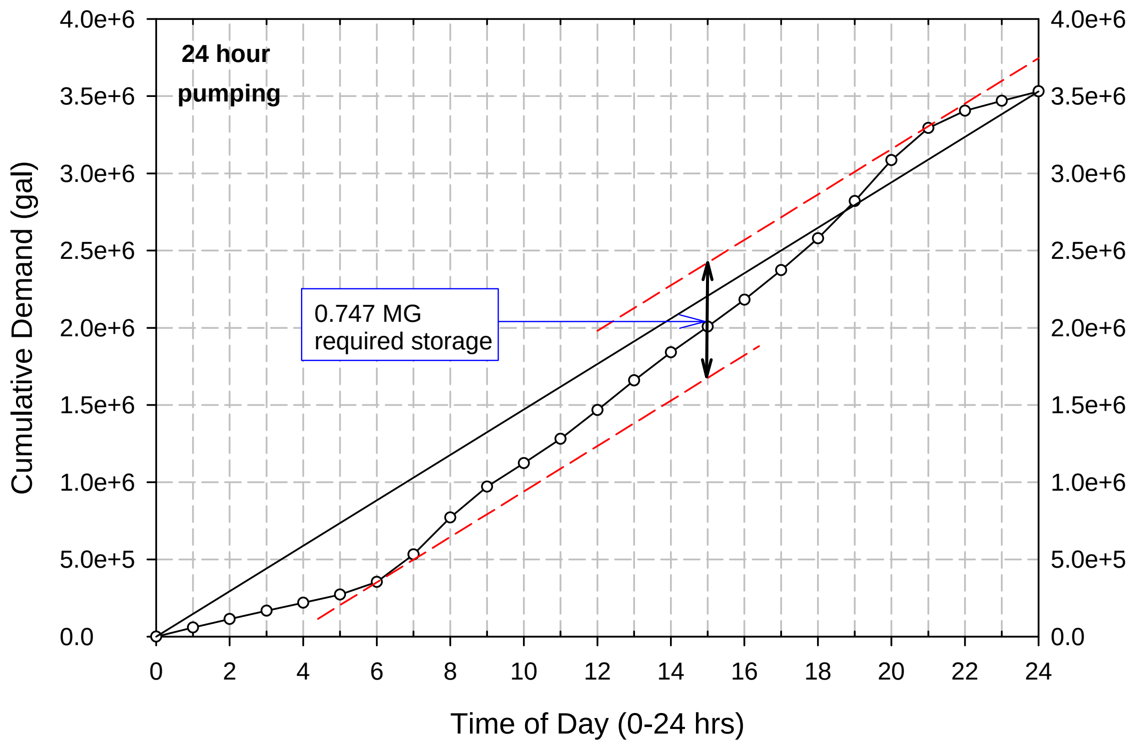



Figure 2. Cumulative Demand

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

$$Q_{equal} = 1.8 \times 0.75 \text{ MG} = \mathbf{1.34\ MG}$$

Total Required Storage

$$Q_{tot} = 2.61 + 1.34 = \underline{\mathbf{3.95\ MG}}$$

## 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 $2,080,000. 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 (Feb 2009 ENRCCI = 8533).

**Solution:**

The director has a valid point. Even with the increase in the CCI, the cost per foot in current (2009) dollars was much lower for the 1970 Milltown project.

| Year | CCI |
|---|---|
| 1970 | 1381 |
| 2009 | 8533 |

| Bid |
|---|
| $ 220,000 |
| $ 2,080,000 |

| length | | cost per ft | |
|---|---|---|---|
| ft | mi | as bid | 2009 dollars |
| 13200 | 2.5 | $ 16.67 | $ 102.98 |
| 7500 | | $ 277.33 | $ 277.33 |

### *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 5000 people over the last 10 years. If you use a linear (arithmetic) model for growth, what population would you predict for 20 years into the future?

1. 50,000
2. 55,000
3. 57,000
4. 65,000
5. none of the above

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

1. 50,000
2. 55,000
3. 57,000
4. 65,000
5. none of the above

Note that $K_e = 0.0118$ yr-1
Which gives y=56,953 ~ 57,000
For 20 years in the future

d. A community has a population of 17,500. 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 2.1 MGD. Their average daily per capita demand is

1. 1750 gpcd
2. 175 gpcd
3. 120 gpcd
4. 80 gpcd
5. none of the above

f. An estimate of the maximum daily demand for the community per questions d and e is.

1. 2.1 MGD
2. 3.8 MGD
3. 5.9 MGD
4. 21 MGD
5. none of the above

g. Drinking water distribution systems

1. Are best designed as grids with many loops
2. Need not provide adequate water storage within the pipes themselves
3. Should be constructed with the smallest pipes that can adequately deliver fire flow and maximum daily demand
4. Should not provide pressures above 150 psi
5. All of the above
6. None of the above

h. Connecting identical pumps in parallel

1. Results in a higher shutoff head downstream of the pumps than if they were in series
2. Results in a higher flow rate at normal operating heads, than if they were in series

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 8 miles from a reservoir at an elevation of 120 ft to a second reservoir at an elevation of 180 ft. The pipeline connecting the reservoirs is 48 inches in diameter. It is concrete with a C of 100, the flow is 25 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:

$$\frac{P_1}{\gamma} + \frac{v_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + Z_2 + h_{L1\to2}$$

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

$$h_T = \frac{P_1}{\gamma} = Z_2 - Z_1 + h_{L1\to2}$$

power equation:

$$P = \frac{Q\gamma h_T}{\eta} = \frac{25MDG\left(62.4\ {}^{lb}\!/\!_{ft^3}\right)100.289\ ft}{0.82}1.54\frac{ft^3}{MGD}1.3558\frac{watts}{ft-lb/s} = 4.0x10^5\ watts$$

And finally the results:

1 calculate headloss

| | | | | |
|---|---|---|---|---|
| hL = | 40.289 | ft = | 12.28009 | m |

2 Calculate the total head

| | | | | |
|---|---|---|---|---|
| hT = | 100.289 | ft = | 30.56809 | m |

3 calculate power

| | | | | |
|---|---|---|---|---|
| P = | 400141.534 | watts = | 400.1415 | KW |

4 cost

| | | |
|---|---|---|
| Energy = | 292303.391 | KW-H/month |
| Cost = | $ 29,230 | per month |

## Good stuff to know

Conversions

7.48 gallon = 1.0 $ft^3$ 1 gal = $3.7854 \times 10^{-3}\ m^3$

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

1 $ft^3/s$ = 449 gal/min

g = 32 $ft/s^2$

$W = \gamma = 62.4\ lb/ft^3 = 9.8\ N/L$

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

Decreasing Rate of Increase:

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

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$^{-1}$) | = $1.1970 \times 10^{-2}$ kJ mol$^{-1}$ |
| 1 erg | = $10^{-10}$ kJ |
| 1 atm | = $1.01325 \times 10^{5}$ Pa |
| 1 Å | = $10^{-10}$ m |
| 1 L | = $10^{-3}$ m$^3$ |

## PROPERTIES OF WATER

| T(°C) | $\rho$, Density (kg · m$^{-3}$) | $\mu$ Viscosity (kg · m$^{-1}$ · s$^{-1}$) | $\sigma$, Surface Tension against Air (J · m$^{-2}$) | $\varepsilon$ 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 | $\mu$ |
| $10^{3}$ | 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 |