CEE 371	May 14, 2009

Final Exam

Closed Book, two sheets of notes allowed
Please answer questions 3, 6 and 7. In addition, answer either question 1 or 2, and answer either question 4 or 5. 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
4 or 5
Circle one from each row. You must answer 3, 6 and 7

1) (**15 pts**) A 10 inch diameter sanitary sewer is designed such that it has a flowing full velocity of 3.5 ft/s. A Manning's roughness coefficient value of 0.013 is assumed. The 10 inch sewer exits sewer manhole (SMH) 1 at an invert out elevation of 98.30 ft.

a) (**9 pts**) What is the invert elevation of the sewer as it enters SMH 2 which is located 285 ft downstream of SMH 1?

Use the Manning equation:

$$Q = \frac{1.49}{n} A R^{0.67} S^{0.5} \qquad V = \frac{1.49}{n} R^{0.67} S^{0.5}$$

And rearrange to solve for the slope (S):

$$S = \frac{Q^2 n^2}{2.22 A^2 R^{1.33}}$$

$$S = \frac{V^2 n^2}{2.22 R^{1.33}}$$

And for a pipe flowing full, R=Area/circumference = $\pi r^2/2\pi r = r/2$:

$$S = \frac{V^2 n^2}{2.22 \left({}^{r}\!/_{2}\right)^{1.33}}$$

$$S = \frac{1.135 V^2 n^2}{(r)^{1.33}}$$

And substituting in the values

$$S = \frac{1.135\left(3.5\frac{ft}{s}\right)^2 0.013^2}{\left({}^{5}\!/_{12}\,ft\right)^{1.33}} = 0.00755$$

So the invert drops by this rate over the 285 ft horizontal distance

Invert @ SMH2 = 98.3-285(0.00755) = $\boxed{\textbf{96.15 ft}}$

b) (**3 pts**) Does the sewer have capacity for a design flow of 0.8 MGD? Show quantitatively.

Compare Q_{design} to Q_{full}.

$$Q_{design} = 0.8x10^6 \frac{gal}{d}\left(\frac{0.13368ft^3}{gal}\right)\left(\frac{1d}{60x60x24s}\right) = 1.24\frac{ft^3}{s}$$

$$Q_{full} = VA = 3.5\frac{ft}{s}\pi\left(10in\left(\frac{1ft}{12in}\right)\Big/2\right)^2 = 1.91\frac{ft^3}{s} = \ (1.24\ MGD)$$

Since $Q_{design} < Q_{full}$, the sewer does have the needed capacity

(N.B. could actually go up to 2.2 cfs @ 80% full)

c) (**3 pts**) What is the desired minimum velocity in the pipe at the design flow? Why?

It is 2 ft/s. The reason is to avoid settling of material from the sewage that might clog the pipe

2) (**15 pts**) Sewer Basics

a) (**3 pts**) Combined sewers were designed to collect and convey what two types of flows to a wastewater treatment plant?

Stormwater and sanitary sewage

b) (**3 pts**) What is a CSO?

Combined sewer overflow; incorporating both types of flows (stormwater and sanitary sewage) usually discharging directly to a receiving water

c) (**3 pts**) List 3 different materials that sewers can be made of.

- Vitrified Clay
- Plastic (e.g., PVC)
- Ductile Iron

d) (**6 pts**) List 3 conditions or situations that require use of a manhole in a sewer system.

Looking for

- Change in sewer alignment
- Change in sewer slope

- Change in sewer diameter
- Beginning or ending of sewer line

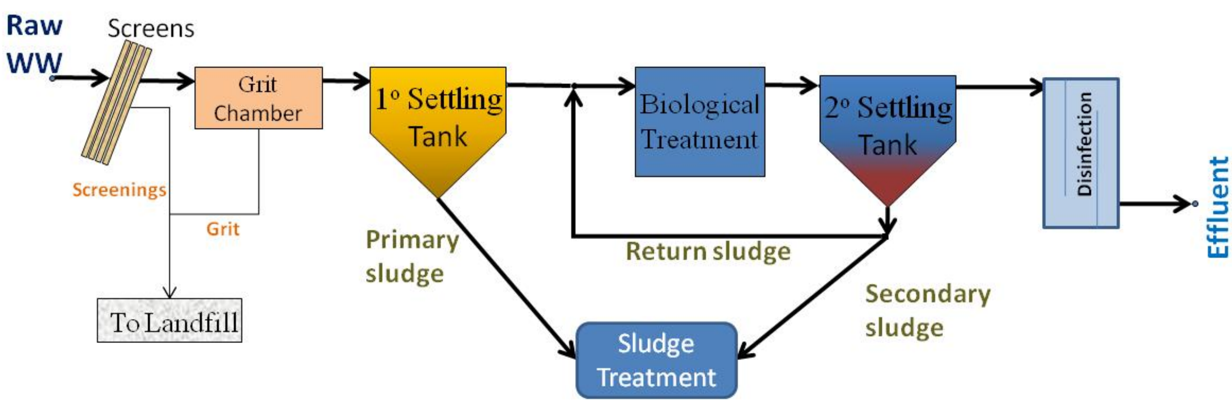
Will accept

- Repairs & Maintenance
- Leak tests

3) (**4 pts**) What does the term "I/I" mean with respect to flow in sewers? Explain.

Inflow/Infiltration: undesired groundwater & stormwater entering the sanitary sewer

4) (**15 pts**) Draw (boxes, lines, arrows) and label (words) a schematic diagram showing <u>all the typical treatment processes and liquid flow paths</u> in an entire conventional municipal wastewater treatment plant using <u>complete-mix activated sludge</u> to provide secondary treatment. Also show and label the residuals produced by certain processes.



5) Biotreatment Basics and Regulations (**15 pts**)

a) (**5 pts**) Activated sludge is an example of a _____**<u>Suspended growth</u>**_________ type of biological wastewater treatment process, while a trickling filter or a biological tower is an example of a ___**<u>Attached growth</u>**_____ type of biological WW treatment process.

b) (4 **pts**) Name three different types of activated sludge systems and explain how they are different in just a few words

Answers could include any three of the following:

- Conventional or **completely –mixed** activated sludge (typically more CSTR than PRF)
- **Tapered Aeration** activated sludge (PFR characteristics; most aeration at the head
- **Step feed** activated sludge (PFR design; influent is added at various points)
- **Pure oxygen** activated sludge (use of pure O2; baffled and covered; higher BOD loading, reduced HRT)

c) (**6 pts**) In 1972 major federal legislation was enacted that later became known as the Clean Water Act. That legislation established water quality goals for the nation's waters and minimum requirements for secondary wastewater treatment.
i) What is the name of the permit system for controlling wastewater discharges?
ii) What are the quantitative requirements for BOD_5 and SS in wastewater discharges from secondary WWTPs?

(i) NPDES: national pollution discharge elimination system
(ii) BOD5 and TSS in the effluent must be less than or equal to 30 mg/L based on a 30 day average, and ≥85% removal of both must be achieved

6) (**40 pts**) You have been selected to design a secondary wastewater treatment plant (WWTP) for Phishville, a Vermont municipality of 15,000 people which has some industry (Ben & Jerry's) that discharges wastewater to the municipal sewer system. The average daily wastewater flow is 2.1 MGD and the raw sewage entering the WWTP has an average BOD_5 of 240 mg/L and average suspended solids of 260 mg/L.

a) (**4 pts**) If the average domestic per capita sewage flow is 115 gpcd, what is the average flow of the industrial wastewater (in MGD)?

Mass balance on the two types of sanitary WW

$$Q_{total} = Q_{domestic} + Q_{industrial}$$

and

$$Q_{domestic} = 15{,}000 people\left(115\frac{gal}{cap-d}\right) = 1{,}725{,}000\,\frac{gal}{d} = 1.725 MGD$$

So:

$$Q_{industrial} = 2.1MGD - 1.725MGD = \mathbf{0.375MGD}$$

b) (**6 pts**) If the average BOD_5 load from the domestic sewage is 0.18 lbs/capita-day, what is the average daily BOD_5 loading (in lbs/day) from the industrial wastewater? What is the population equivalent to this BOD_5 loading?

$$Domestic\ Loading = 15{,}000 people\left(0.18\frac{lb}{cap-d}\right) = \mathbf{2,700\frac{lb}{d}}$$

$$Total\ Loading = 2.1x10^6\frac{gal}{d}240\frac{mg}{L}\left(\frac{g}{1000mg}\right)\left(\frac{lb}{453.59g}\right)\left(\frac{3.7854L}{gal}\right) = \mathbf{4203\frac{lb}{d}}$$

$$Industrial\ Loading = total\ loading - domestic\ loading = 4{,}203\frac{lb}{d} - 2{,}700\frac{lb}{d}$$
$$= \mathbf{1,503\frac{lb}{d}}$$

So now the population equivalent is calculated from the per capita domestic loading

$$Population\ Equivalent = \frac{1{,}503\frac{lb}{d}}{0.18\frac{lb}{cap-d}} = \mathbf{8,352\ people}$$

c) (**4 pts**) The wastewater is treated in two parallel primary sedimentation tanks. What is the diameter of each tank for a design overflow rate of 600 gpd/ft^2 at average flow?

Two trains, so the flow through each is one-half the total flow or 1.05 MGD

Now since:

$$V = {}^{Q}/_{A}$$

Then:

$$A = \frac{Q}{V} = \frac{1.05x10^6 \frac{gal}{d}}{600 \frac{gal}{d-ft^2}} = 1{,}750 ft^2$$

So to get the diameter, we use simple geometry:

$$A = \pi \left(\frac{D}{2}\right)^2$$

Rearranging:

$$D = 2\sqrt{A/\pi} = 2\sqrt{1{,}750 ft^2 / 3.1415} = \mathbf{47.2 ft}$$

Or nominally, **48 ft**

d) (**6 pts**) Primary treatment achieves 65% suspended solids removal and 35% BOD_5 removal. What are the average BOD_5 and SS concentrations (mg/L) and daily loadings (1b/day) entering the secondary treatment process?

First for BOD:

$$BOD = (1 - 0.35)240 \frac{mg}{L} = \mathbf{156 \frac{mg}{L}}$$

$$BOD\ Loading = QxBOD = 2.1x10^6 \frac{gal}{d} 156 \frac{mg}{L} \left(\frac{g}{1000mg}\right)\left(\frac{lb}{453.59g}\right)\left(\frac{3.7854L}{gal}\right) = \mathbf{2{,}732 \frac{lb}{d}}$$

Next for SS:

$$SS = (1 - 0.65)260 \frac{mg}{L} = \mathbf{91 \frac{mg}{L}}$$

$$SS\ Loading = QxSS = 2.1x10^6 \frac{gal}{d} 91 \frac{mg}{L} \left(\frac{g}{1000mg}\right)\left(\frac{lb}{453.59g}\right)\left(\frac{3.7854L}{gal}\right) = \mathbf{1{,}594 \frac{lb}{d}}$$

e) (**20 pts**) A complete mix activated sludge process is to be used for biological treatment. Assume average flow conditions and the primary treatment performance as in part d) above. Assume the following for the activated sludge process:
- Plant effluent BOD_5 of 12 mg/L
- Biomass yield (Y) of 0.54 kg biomass / kg BOD
- Endogenous decay rate (k_d) = 0.05 day^{-1}
- Solids Retention Time (θ_C) = 8 days
- MLVSS concentration in the aeration tank (X) of 2700 mg/L
- Waste and recycle solids concentration (X_R) of 12,000 mg/L

Make calculations based on a single train, i.e., total plant flow for the following:

i) Determine the aeration tank volume in cubic meters.
ii) Determine the design hydraulic detention time, in hours.
iii) Determine the mass (dry) and volumetric rates of secondary sludge wasted (kg/day, m^3/day).

iv) Determine the sludge recycle (return) flow rate in m^3/day and the recycle ratio.

v) Determine the food to microorganism ratio.

Part i

For this use the combined activated sludge model:

$$\frac{1}{\theta_c} = \frac{YQ(S_o - S)}{XV} - k_d$$

Convert from MGD to cubic meters per day: (2.1 MGD = 7948.5 m^3/d)

$$\frac{1}{8d} = \frac{0.54\left(7948.5\frac{m^3}{d}\right)(156 - 12)\frac{mg}{L}}{2700\frac{mg}{L}V} - 0.05d^{-1}$$

Now solve for V

V=1308 m^3

Part ii

$$t_R = \theta = \frac{V}{Q} = \frac{1308m^3}{7948.5\frac{m^3}{d}} = \mathbf{0.164d = 3.95h}$$

Part iii

$$secondary\ sludge\ mass\ wasting\ rate = Q_W x_r = \frac{XV}{\theta_c}$$

$$mass\ wasting\ rate = Q_W x_r = \frac{XV}{\theta_c} = \frac{2.7\frac{Kg}{m^3}1309m^3}{8d} = \mathbf{441\frac{Kg}{d}}$$

$$volumetric\ wasting\ rate = Q_W = \frac{Q_W x_r}{Q_W} = \frac{441\frac{Kg}{d}}{12\frac{Kg}{m^3}} = \mathbf{36.8\frac{m^3}{d}}$$

Part iv

Use mass balance equations to find Qr and R

$$Q_r = \frac{QX - Q_w x_r}{x_r - x} = \frac{7948.5\frac{m^3}{d}2.7\frac{Kg}{m^3} - 441\frac{Kg}{d}}{12\frac{Kg}{m^3} - 2.7\frac{Kg}{m^3}} = \mathbf{2260\frac{m^3}{d}}$$

$$R = \frac{Q_r}{Q} = \frac{2260\frac{m^3}{d}}{7948.5\frac{m^3}{d}} = \mathbf{0.28}$$

Part v

$$F/_M\, ratio = \frac{QS_o}{XV} = \frac{7948.5\frac{m^3}{d}156\frac{mg-BOD}{L}\left(\frac{1000L}{m^3}\right)\left(\frac{Kg}{10^6mg}\right)}{2.7\frac{Kg-VSS}{m^3}1308m^3} = \mathbf{0.35\frac{Kg - BOD/d}{Kg - VSS}}$$

7) (**26 pts**) More work for your firm! Phishville, the municipality from Problem 6, has hired you to consider their drinking water supply and treatment needs for the future. Assume that average industrial water demand is the same now and in the future, and is equal to the industrial wastewater flow you determined for Problem 6, part a).

a) (**4 pts**) If the average domestic per capita water demand is 110 gpcd, and the population is projected to grow by 350 people per year, estimate the average daily water demand (in MGD) for Phishville in 20 years.

$$Pop_{t+20} = Pop_t + 20yr(r_{linear}) = 15{,}000 + 20yr(350yr^{-1}) = 22{,}000$$

$$Q_{avg} = Q_{domestic} + Q_{industrial}$$

$$Q_{avg(t+20)} = 22{,}000(110gpcd)\left(\frac{MG}{10^6 gal}\right) + 0.375MGD = 2.42MGD + 0.375\ MGD$$
$$= \mathbf{2.8}\ \boldsymbol{MGD}$$

b) (**12 pts**) The drinking water source for Phishville is a reservoir and the water is treated by conventional processes. The water surface elevation in the clear well at the end of the treatment plant is 160 ft. In order to supply adequate pressure for the municipality, the hydraulic grade line (HGL) of the water system must be at elevation 330 ft. Treated water is pumped through 2 miles of 16 inch diameter ductile iron pipe (C_{HW} = 120) to the water distribution system. If the ratio of maximum day demand to average day demand is 1.5, what is the required pump power (in horsepower) to supply $Q_{max\ day}$ in the future (20 years from now)?

In this case, you're pumping from a clearwell with a free water surface elevation (i.e. at atmospheric pressure) at 160ft to the system (2 miles away) with the goal of achieving an HGL of 330 ft. This might mean that there is elevated storage in the system with a free surface elevation of 330 ft, or it might mean that there is no storage and the pressure at the end of the main is equivalent to a static head of a column of water rising to 330 ft above sea level.

So considering the peaking factor:

$$Q = 1.5 * 2.8MGD = 4.2\ MGD$$

Or it may be convenient to calculate the future max day flow in cfs.

$$Q = 1.5\left(2.8x10^6\frac{gal}{d}\right)\frac{0.13368ft^3}{gal} = 6.5\frac{ft^3}{s}$$

Ignoring minor losses:

$$H_{pump} = H_{static} + h_f$$

And the static head is just the HGL change:

$$H_{static} = 330-160 = 170\ ft$$

For the h_f, use the Hazen Williams equation

$$Q = 0.432CD^{2.63}\left(\frac{h_f}{L}\right)^{0.54}$$

$$h_f = L\left[Q/\left(0.432CD^{2.63}\right)\right]^{1.85}$$

$$= 2x5280\,ft\left[6.5cfs/\left(0.432(120)\left(16/12\right)^{2.63}\right)\right]^{1.85}$$

$$= 56\,ft$$

Or if you prefer to work in MGD:

$$Q = 0.279CD^{2.63}\left(\frac{h_f}{L}\right)^{0.54}$$

$$h_f = L[Q/(0.279CD^{2.63})]^{1.85} = 10.6\frac{Q^{1.85}L}{C^{1.85}D^{4.87}}$$

$$h_f = 10.6\frac{4.2^{1.85}10{,}560ft}{120^{1.85}\left(16/12\right)^{4.87}} = 55.7ft$$

Now, we can get H_{pump}:

$$H_{pump} = 170\text{ ft} + 56\text{ft} = 226\text{ ft}$$

Assuming an efficiency of 85%:

$$P = \frac{Q\gamma h_T}{550\eta} = \frac{6.5\frac{ft^3}{s}62.4\frac{lb}{ft^3}226ft}{550(0.85)} = \mathbf{196\ hp} = 107{,}500\,ft-lb/s$$

c) (**4 pts**) A developer wants to build homes in an undeveloped area of Phishville adjacent to the existing distribution system. The ground elevations are 300 to 310 ft in this area. Can the current water system provide adequate pressure for this development? Show quantitatively.

Since the system HGL is at 330 ft (elevation of storage tank)

Max Static Pressure = HGL-z = 330ft – 300 ft = 30 ft

$$pressure = 30ft\left(62.4\frac{lb}{ft^3}\right)\left(\frac{1ft}{12in}\right)^2 = \mathbf{13}\ \frac{\mathbf{lb}}{\mathbf{in^2}}$$

This is not really adequate as general criteria call for at least 35 psi.

d) **(6 pts)** What component of the Phishville drinking water system is designed to provide water in the event of a short-term, or emergency, loss of the water source? What two other types of water demands are considered in the design of this component of the water system?

Distribution Storage

- Fire fighting demand: fire volume
- Peak hourly demands: equalizing storage volume

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

Water Properties:

At 60 ºF, $\nu = 1.217 \times 10^{-5}$ ft^2/s , $\mu = 2.359 \times 10^{-5}$ lb-sec/ft^2 , γ = 62.4 lb/ft^3

At 10 ºC, $\nu = 1.306 \times 10^{-6}$ m^2/s , $\mu = 1.307 \times 10^{-3}$ kg/m-s , ρ = 999.7 kg/m^3

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)	ρ, Density ($kg \cdot m^{-3}$)	μ, Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)	σ, Surface Tension against Air ($J \cdot m^{-2}$)	ε, Dielectric Constant ($C \cdot V^{-1} \cdot m^{-1}$)	pK_w, Ionization Constant ($mol^2 \cdot L^{-2}$)
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