1.85 WATER AND WASTEWATER TREATMENT ENGINEERING
TAKE-HOME MID-TERM EXAM
DUE FRIDAY NOVEMBER 4, 2005 AT 1:00 PM

This is an open-book exam, with the exception that you are asked to restrict your use of Internet sources to the links included on the 1.85 course webpage and to routine information sources like unit conversions. Unlike the homework, collaboration is not permitted—please do not work with others on this exam. If you have questions, you can reach Pete Shanahan.

1. (28 points)
   Stormwater detention ponds are intended to serve both to attenuate flood flows by providing temporary water storage and to improve stormwater quality by removing sediment. The Massachusetts Stormwater Technical Handbook recommends that stormwater detention ponds provide an average of 24 hours detention time. The guidelines also indicate that ponds can be between 3 and 12 feet (1 and 4 meters) deep.
   Given these guidelines, what size particle can be entirely removed in:
   a. A 3-foot (1-meter) deep pond? d = 3.6 um under creeping flow conditions – see attached calculation. Note that solution should include check that creeping flow conditions are satisfied.
   b. A 12-foot (4-meter) deep pond? d = 7.2 um under creeping flow conditions – see attached calculation.

   Provide your solutions in metric units. You can assume Type I settling and a particle density of 2.6 g/cm^3.
   c. Do you think the 24-hour detention pond guideline is adequate to ensure that detention ponds will remove sediment from the stormwater?
      This could be argued either way. If you set a hard-and-fast condition that all silt and sand must be removed, then the guideline is inadequate. Alternatively, one can argue that based on these calculations, all but the smallest fraction of sediment is removed, and therefore the ponds are adequate. Two key factors that we do not know are: 1. What is the distribution by mass over the different particle sizes? Presuming most mass is in the largest particles, this treatment would remove a substantial percentage of the incoming sediment and from that viewpoint is adequate. 2. What is the impact of the sediment that passes through? If lots of clay were to get through and coat the landscape with a whitish-gray clay coating, then the pond size is inadequate. My overall sense is that the guideline is adequate, but marginal.
   d. Do you think it is realistic for the state to give a single detention-time guideline when the pond depth is variable? (Phrased another way, do you think the state should provide different detention-time guidelines for 1-meter deep and 4-meter deep ponds.) Why or why not?
      First of all, a fourfold difference in pond depth translates into a twofold difference in sediment size removed. So, the ponds deliver improved performance in terms of removal at the cost of much larger ponds—not a very favorable tradeoff. Further, this difference is occurring at the small end of the particle size distribution, and presumably translates into relatively little mass. Finally, the simple guideline makes for simple implementation

and enforcement. From these standpoints, one could argue the simple rule makes practical sense.

One could instead argue that detention pond performance should be based on actual calculations to ensure the pond design achieves the particular performance goal specified by regulations. The calculations are not that complicated, an engineer is necessary to design the ponds in the first place, and it is not too much to ask that a design be done, rather than a cookbook solution. Many states require this sort of approach.

My opinion is that this is a close call, but given the relative insensitivity in performance to size, the simple guideline is acceptable.

I was not looking for any particular answer for parts c and d – simple a clear, defensible, and well presented argument for your answer.

1. $T_R = 24$ hours

$V_s T_R = 1 \text{ m}$ or $V_s T_R = 4 \text{ m}$

$$V_s = \frac{1}{24} \frac{m}{hr}$$

$$= 0.042 \frac{m}{hr} = 1 \frac{m}{d}$$

$$= 1.2 \times 10^{-5} \frac{m}{s}$$

Assume creeping flow

$\rho_s = 2.6 \text{ g/cm}^3$ $\eta = 10^{-3} \frac{m \cdot kg}{s}$

a. $$V_s = \frac{g d^2 (\rho_s - \rho_w)}{18 \eta} = 1.2 \times 10^{-5} \frac{m}{s}$$

$$= \frac{9.8 \frac{m}{s^2} \; 1600 \frac{kg}{m^3} \; d^2 m^2}{18 \; 10^{-3} \frac{m \, kg}{s}} = 1.2 \times 10^{-5}$$

$$d^2 = \frac{1.2 \times 10^{-5} \cdot 18 \cdot 10^{-3}}{9.8 \cdot 1600}$$

$$= 1.3 \times 10^{-11} \text{ m}^2$$

$$d = 3.6 \times 10^{-6} \text{ m} = 3.6 \ \mu m$$

b. For $V_s T_R = 4$ m

$$d = 7.2 \ \mu m$$

1 continued

Check creeping flow assumption:

$$Re = \frac{\rho V_s d}{\eta} = \frac{10^3 \frac{kg}{m^3} \; 1.2\times10^{-5} \frac{m}{s} \; 7.2\times10^{-6} m}{10^{-3} \frac{kg}{m\cdot s}}$$

$$= 8.6\times10^{-5} \ll 1$$

assumption checks and would hold for smaller particle in part a also.

2. (28 points)
On-site wastewater treatment via a septic tank and disposal to a subsurface leaching field is a common means to manage wastewater in rural and suburban areas. The technology depends upon the soil to act as a filter to remove bacteria and viruses. Please answer the following essay questions regarding your expectations of the mechanisms and effectiveness of this filtration technique.

a. Bacteria and viruses are generally negatively charged. If the soil below the leaching field is a sandy soil that is fully saturated with water, would you expect the soil to be generally effective or ineffective in removing bacteria and viruses? Why or why not?
In essence, the soil acts as a slow sand filter. The negatively charged bacteria and viruses will not be readily filtered by the also negatively charged soil particles. The primary removal mechanism is straining (followed by biodegradation), which will not be very effective against small particles such as bacteria and particularly viruses.

b. Experimental data show that virus removal by soil is generally more effective from regular tap water than from distilled water. Provide an explanation for this observation.
Tap water has some dissolved cations that can attach to the negatively charged bacteria and viruses, creating a diffuse double layer that reduces electrical repulsion and enhances filtration. Distilled water does not the dissolved ions to create this effect.

c. Studies have shown that the number of fecal bacteria found in the ground water below a newly constructed leaching field is higher after it first starts to be used but then decreases with time until it reaches an approximately steady level. Provide an explanation for this observation.
This is very much like a filter ripening process for a slow sand filter. The soils beneath the leaching field act as a slow sand filter, except the schmutzdecke is called a "clogging mat". It takes a while for the bacterial cultures that biodegrade wastewater to become established, so bacteria travel through more readily during the start-up period before the clogging mat is established.

d. Very coarse sands allow fast infiltration of wastewater and thus enable smaller, less expensive leaching fields to be constructed. However, many states ban septic systems in very coarse sands. Provide a technical explanation for why leaching fields would be banned in very coarse sands.
The very coarse sands have a couple of drawbacks. First, they provide less effective physical straining, which is one of the main mechanisms of treatment in a subsurface leaching field. Second, they allow rapid travel of wastewater to the water table. Residence time in the subsurface is important in providing time for first-order waste degradation processes to act.

3. Short answer questions (3 points each, 30 points total).
For each of the following indicate if the designated technology is appropriate for the indicated water-quality problem. Explain why or why not (answer in no more than a few sentences).

a. A 60-micron household filter for cryptosporidium.
Not appropriate – This filter would not work in removing 5-um cryptosporidium spores.

b. Ion exchange for waste contaminated by radioactive cesium and strontium.

Appropriate – Despite the radioactivity, cesium is cesium and strontium is strontium. These cations can be effectively removed by ion exchange.

c. A strong-base ion exchange resin for nitrate.

Appropriate – Strong-base ion exchange resins remove anions like nitrate, so this is appropriate technology.

d. Slow sand filtration for highly turbid water.

Not appropriate – Slow sand filtration is effective only against relatively low turbidity waters, with less than 10 to 50 NTU.

e. Activated carbon for ground water contaminated by BTEX (benzene, toluene, ethylbenzene, and xylene) from a gasoline spill.

Appropriate – Activated carbon effectively adsorbs organic compounds and is effective for BTEX (although air stripping is usually more cost effective).

f. Filtration for taste and odor.

Not appropriate – Taste and odor is usually associated with dissolved organic matter which would not be appreciably removed by filtration.

g. Lime treatment for hardness of 90 mg/L as $CaCO_3$.

Appropriate – Lime treatment can reduce hardness to about 50 mg/L as $CaCO_3$.

h. Ion exchange for hardness of 90 mg/L as $CaCO_3$.

Appropriate – In fact, small ion exchange units are often used for households to reduce hardness below what the public water system delivers.

i. Lime treatment for iron.

Appropriate – Addition of lime raises the pH which enhances oxidation and precipitation of iron and manganese.

j. Suspended sediment removal in a vigorously mixed fully-mixed tank.

Not appropriate – mixing will keep sediment in suspension, preventing removal

4. (14 points)
In designing a sedimentation basin, indicate whether the first stated design characteristic would require a smaller, larger, or same size basin to achieve the same sediment removal as the second stated characteristic. Give a short (one or two sentences) explanation of your answer.

a. Large particles vs. small particles of the same density with Type I settling.
   Smaller tank – large particles have higher settling velocity which would allow a higher overflow rate
b. A 3-meter deep tank vs. a 5-meter deep tank.
   Same size tank – removal is a function only of overflow rate, which is unchanged by tank depth
c. Type II vs. Type I settling of influent particles of the same size and density.
   Smaller tank – Type II settling causes settling velocities to increase as the particles coagulate and form larger particles. Therefore overall residence time can be less.
d. Mineral (e.g., quartz) particles vs. organic particles of the same size.
   Smaller tank – mineral particles have a higher density and therefore higher settling velocity
e. Particles with a single settling velocity, V_s, vs. particles with a distribution of settling velocities with a mean settling velocity equal to V_s.
   A smaller tank is needed for the uniform particles. A tank of the same size would settle particles with a velocity distribution greater than or equal to the mean settling velocity, but only a decreasing fraction of the particles with lesser settling velocities.
f. A long, narrow tank vs. a circular center-feed tank.
   A long narrow tank is more effective in that it reduces short circuiting. Therefore the long narrow tank can be smaller.
g. Average supply water temperature of 20°C vs. 5°C
   Viscosity and water density, and therefore settling velocity, are temperature dependant, although viscosity varies much more than density. At 20C, η = 1.01 cP while at 5C, η = 1.52 cP (see Appendix C of Reynolds and Richards). At 20C, the settling velocity is 50% higher than at 5C, and the tank would need be only 2/3 the size.