HOMEWORK 6 - SOLUTIONS

1.

The answer depends upon your location. The following provides an example of the level of detail expected.

The town of Acton, MA does not have curbside pickup. Residents bring their trash and recyclables to a transfer station located on Route 2 near the center of town. Trash is deposited to an enclosed transfer building. A front-end loader places the trash in truck trailers for hauling to a trash-to-energy facility in North Andover, Massachusetts.

The trash-to-energy facility is operated by Wheelabrator Environmental and has a contract with the North East Solid Waste Committee (NESWC), a group that includes the towns of Acton, Andover, Arlington, Bedford, Belmont, Boxborough, Burlington, Carlisle, Dracut, Hamilton, Lexington, Lincoln, Manchester, North Andover, North Reading, Peabody, Tewksbury, Watertown, Wenham, Westford, West Newbury, Wilmington, and Winchester. As originally conceived, revenues from energy generation at the plant were to largely defray costs to the towns. As it turns out, low prices for energy, high environmental control costs, and unfavorable contract terms have made NESWC a very expensive proposition for the towns involved. Solid waste disposal fees are three to four times the market rate for the area and a major expense for the towns.

The North Andover facility is known as North Andover RESCO and is operated by Massachusetts Refusetech, Inc. It has been heavily criticized by local environmentalists as a cause of respiratory illnesses in the surrounding communities and for its emissions of mercury. The plant, constructed in 1985, is designed to handle 1500 tons of trash per day and generate 40 Megawatts of electricity (http://www.wheelabrator-northandover.com/plant_intro.html).

2.

For these chlorinated solvents, a zero-valence iron PRB is appropriate.

For TCE: $t_{½}$ = 6 hours ? k = 0.69/ $t_{½}$ = 0.115 hr^{-1} = 2.8 day^{-1}
For TCA: $t_{½}$ = 1 hours ? k = 0.69/ $t_{½}$ = 0.69 hr^{-1} = 17 day^{-1}

PRB performance is given by: $C(t) = C_0\, e^{-kt}$

Desired performance:
TCE: C_0 = 1500 µg/L ? C(t) = 5 µg/L (MCL)
TCA: C_0 = 20,000 µg/L ? C(t) = 200 µg/L (MCL)

We have C(t), C_0, and k, need to solve for t:
$t = -[\ln(C(t)/C_0)]/k$

For TCE: t = -[ln(5/1500)]/2.8 = 2.0 days
For TCA: t = -[ln(200/20000)]/17 = 0.3 days

PRB design is controlled by TCE reaction. PRB must provide 2 days residence time.

Hydraulic Design:

n = 0.3 K_{PRB} = 2 x 10^{-2} cm/sec = 57 ft/day for PRB

n = 0.25 K_A = 1.6 x 10^{-2} cm/sec = 45 ft/day for aquifer

The interaction between the aquifer and the PRB is complicated: the higher K of the PRB will cause some focusing of flow into the PRB and a decrease in head in the aquifer around the PRB.

One possible approximation is to assume the aquifer head is unchanged at either side of the PRB. In other words that the gradient through the PRB is the same as in the aquifer is i = 0.0055. This assumption neglects the fact that the PRB will decrease heads in the aquifer in the immediate vicinity of the PRB.

Ground-water velocity is: v = Ki/n = 57 ft/day x 0.0055 / 0.3 = 1.0 ft/day
v = 2 x 10^{-2} cm/sec x 0.0055 x 86400 sec/day / 0.3 = 32 cm/day

PRB thickness = B = vt = 1 ft/day x 2 days = 2 feet   = 32 cm/day x 2 days = 64 cm

Another possible assumption is that continuity is preserved between the cross-sectional area, A, of the PRB and the corresponding area in the aquifer. This assumption neglects the fact that flow will focus into the PRB and thus A in the aquifer is effectively larger than A in PRB.

$Q_A = Q_{PRB}$
$K_A\ i_A\ A = K_{PRB}\ i_{PRB}\ A$
$i_{PRB} = K_A i_A / K_{PRB}$ = 1.6 x 10^{-2} x 0.0055 / 2 x 10^{-2} = 0.0044

Ground-water velocity is: v = Ki/n = 57 ft/day x 0.0044 / 0.3 = 0.84 ft/day
v = 2 x 10^{-2} cm/sec x 0.0044 x 86400 sec/day / 0.3 = 25 cm/day

PRB thickness = B = vt = 0.84 ft/day x 2 days = 1.7 feet = 25 cm/day x 2 days = 50 cm

Note that the “true” velocity is between these two extremes, but the differences are probably within the accuracy of measurement techniques anyway. To play it safe, one would probably specify a PRB thickness of 3 feet.

3.

Risk level = I * CSF = C * CR * EF *ED / W / AT * CSF

From EPA IRIS web site, CSF for pentachlorophenol = 0.12 per mg/kg/day

C = 50 µg/L = 0.05 mg/L
CR = 5 L/day
EF = 7 days/week
ED = 34 weeks
W = 60 kg
AT = 70 years = 70*365 days

I = 0.05 mg/L * 5 L/day * (7*34) days / 60 kg / (70*365) days
= 3.9 x 10^{-5}

Risk level = I * CSF = 3.9 x 10^{-5} * 0.12 mg/kg/day = 5 x 10^{-6}

An MIT education is not as hazardous as you might think!

Difficulties arose in specifying the exposure frequency, EF = 7 days/week, and the exposure duration, ED = 34 weeks. Several gave the answer that EF = 7 days/week x 34 weeks/year = 238 days/year and then that ED = 34 weeks/52 weeks/year = 0.65 year

This computation underestimates the exposure by a factor of 0.65. Think of it in terms of the mass of contaminant to which the individual is exposed:

M = C * CR * EF *ED = 0.05 mg/L * 5 L/day * 7 days/week * 34 weeks = 59.5 mg

The intake for a 60 kg individual over a 70-year lifetime is then I as calculated above, namely I = M / W / AT.

36. a. $F_L = W \sin\beta - W \cos\beta \tan\phi = W(\sin\beta - \cos\beta \tan\phi)$

Compute per unit width of liner

β = arctan 0.36 = 19.8°

ϕ = 17°

$$W = 26.6\ m \cdot 1.5\ mm \cdot 0.94\ \frac{g}{cm^3}\ 980\ \frac{cm}{s^2} \cdot \frac{1\ kg}{1000\ g} \cdot \frac{1\ cm}{10\ mm} \cdot \frac{100\ cm}{m}$$

$$= 367\ \frac{kg\ m}{s^2}\ \frac{1}{m}$$

$$= 367\ \frac{N}{m}$$

$$F_L = 367\ (0.34 - 0.29) = 18.7\ \frac{N}{m}$$

$$F_A = g\ \rho_L\ t\ L_A \tan\phi$$ * See note

$$= 980\ \frac{cm}{s^2}\ 0.94\ \frac{g}{cm^3}\ 0.15\ cm\ \ 6\ m\ \tan 17\ \ 100\ \frac{cm}{m} \cdot \frac{1\ kg}{1000\ g}$$

$$= 25\ \frac{N}{m}$$

OK without sand bags $FS = \frac{F_A}{F_L} = 1.4$

* Note: L_A is used only to compute W. Area over which W is exerted does not affect friction and is irrelevant to problem.

b. Additional weight of sand bags

3 sand bags per 3 m liner width

$$\frac{3 \times 20\ kg}{3\ m} = 20\ \frac{kg}{m}$$

37. con't

$$W' = \left(26.6\ \cancel{m} \cdot 0.15\ \cancel{cm} \cdot 0.94\ \frac{\cancel{g}}{\cancel{cm^3}} \cdot \frac{1\ kg}{1000\ \cancel{g}} \cdot \left(100\ \frac{\cancel{cm}}{m}\right)^2 + 20\ \frac{kg}{m}\right) \times 9.8\ \frac{m}{s^2}$$

$$= \left(37.5\ \frac{kg}{m} + 20\ \frac{kg}{m}\right) \times 9.8\ \frac{m}{s^2}$$

$$= 564\ \frac{kg \cdot m}{s^2} \qquad = 564\ \frac{N}{m}$$

$$F_L' = W' \sin\beta - W' \cos\beta \tan\phi = 191 - 162$$

$$= 28.8\ \frac{N}{m} \quad > \quad F_A = 25\ \frac{N}{m}$$

Liner will slip!

c. Solution: throw bags on top of anchorage during installation