Homework #3 - Solutions

Released: 10/17/2014 (Fri) - Due: 10/22/2014 (Wed), in class

The homework will NOT be graded, but we will check for MISSING ANSWERS and CHEATING. Note that a cheated homework will get 80% of the lowest score in the class. You can give the answers **either** in English **or** Korean.

1. [Hydrology] A lake is 12 km in length by 2.5 km in width. The inflow for the month of April is 3.26 m^3/s and the outflow is 2.93 m^3/s. The total monthly precipitation is 15.2 cm and the evaporation is 10.2 cm. The seepage out of the lake is estimated to be 2.5 cm. Estimate the change in storage during the month of April.

Answer) Let's list the input and output processes taking the system boundary as the lake.

Input processes

- *Inflow,* $Q_{in} = 3.26\ m^3/s$
- *Precipitation,* $P = 15.2\ cm/month$

Output processes

- *Outflow,* $Q_{out} = 2.93\ m^3/s$
- *Seepage out,* $I_{out}' = 2.5\ cm/month$
- *Evaporation,* $E = 10.2\ cm/month$

From the mass balance of the system boundary, the change in storage, ⊿S, can be calculated as follows:

$$\Delta S = Q_{in} + P - Q_{out} - I_{out}' - E$$

$$= (3.26 - 2.93)\ m^3/s \times (86400 \times 30)\ s/month$$

$$+ (15.2 - 2.5 - 10.2)\ cm/month \times \left(10^{-2}\ m/cm\right) \times \left(12\ km \times 2.5\ km \times 10^6\ m^2/km^2\right)$$

$$= 1.61 \times 10^6\ m^3/month$$

2. [Hydrology] A 4000-km^2 watershed receives 102 cm of precipitation in a year. The average flow of the river draining the watershed is 34.2 m^3/s. Infiltration is estimated to be 5.5 × 10^{-7} cm/s and evapotranspiration is estimated to be 40 cm/year. Determine the change in storage in the watershed over a year. Compute the runoff coefficient for this watershed assuming that all of the flow in the river is due to runoff.

Answer) Let's list the input and output processes taking the watershed as the system boundary.

Input processes

- *Precipitation, P = 102 cm/year*

Output processes

- *River flow out, Q_{out} = 34.2 m^3/s*
- *Infiltration, I = 5.5 × 10^{-7} cm/s*
- *Evapotranspiration, E_T = 40 cm/year*

From the mass balance of the system boundary, the change in storage, ΔS, can be calculated as follows:

$$\Delta S = P - Q_{out} - I - E_T$$

$$= 102\ cm/year - 34.2\ m^3/s \times \frac{100 cm/m \times (86400 \times 365)\ s/year}{4000\ km^2 \times 10^6 m^2/km^2}$$

$$- 5.5 \times 10^{-7} cm/s \times (86400 \times 365)\ s/year - 40\ cm/year$$

$$= 102\ cm/year - 27.0\ cm/year - 17.3\ cm/year - 40\ cm/year$$

$$= 17.7\ cm/year$$

We assume that the runoff, R is equal to Q_{out}. So the runoff coefficient is calculated as:

$$Runoff\ coefficient = \frac{R}{P} = \frac{Q_{out}}{P} = \frac{27.0\ cm/year}{102\ cm/year} = 0.26$$

3. [Hydrology] Two piezometers have been placed along the direction of flow in a confined aquifer that is 30.0 m thick. The piezometers are 280 m apart. The difference in piezometric head between the two is 1.4 m. The aquifer hydraulic conductivity is 50 m/day, and the porosity is 0.2. Estimate the travel time for water to flow between the two piezometers.

Answer) First, calculate the Darcy velocity, v.

$$v = K \cdot \frac{\Delta h}{L} = (50\ m/day) \cdot \frac{1.4\ m}{280\ m} = 0.25\ m/day$$

Then, the seepage velocity, v′ is

$$v' = \frac{v}{\eta} = \frac{0.25\ m/day}{0.2} = 1.25\ m/day$$

This is the actual linear velocity of the groundwater flow between the two piezometers.

The travel time is calculated as

$$t = \frac{L}{v'} = \frac{280\ m}{1.25\ m/day} = 224\ days$$

4. [Water quality] Look up related textbooks or the Internet to answer the following questions on different types of pollutants.

i) List two types each of pathogenic viruses, bacteria, and protozoa and list the symptoms or diseases when humans are infected by each pathogen. (병원균으로 작용하는 바이러스, 박테리아, 원생동물을 각 2종씩 열거하고, 각 병원균에 감염되었을 때 사람에게 나타나는 증상 또는 병명을 말하시오.)

Answer) Following are the examples of well known pathogens and the consequences when humans are infected by them.

a) Viruses

Coronavirus: causes colds, one strain that belongs to Coronarirus causes SARS (severe acute respiratory syndrome)

Rhabdovirus: one species that belongs to this family, Rabies virus, causes rabies

Orthomyxoviridae: a family of viruses that cause influenza

Norovirus: gastroenteritis

Hepatitis A-E: vial hepatitis (liver inflammation)

b) Bacteria

Salmonella: typhoid fever, food poisoning

Escherichia coli O157:H7: hemorrhagic diarrhea, kidney failure

Shigella: dysentery

Campylobacter jejuni: food poisoning

Vibrio cholerae: cholera

Helicobacter pylori: gastritis, nausea, peptic ulcers, stomach cancer

c) Protozoa

Giardia lamblia: diarrhea, malaise, steatorrhoea

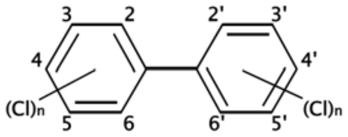
Cryptosporidium parvum: diarrhea, anorexia, nausea

Entamoeba histolytica: dysentery and liver abscess

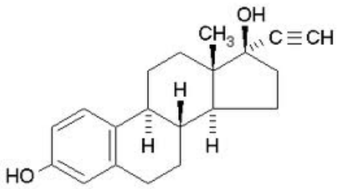
ii) List at least five different endocrine disrupting chemicals (EDCs) and draw their chemical structures. (내분비계교란물질을 최소 5가지 열거하고, 각 물질의 화학구조를 그리시오.)

Answer) Following are the examples of well known EDCs.

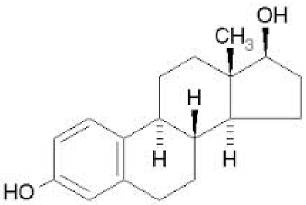
Polychlorinated biphenyls (Note that these are not a single compound, but a group of compounds having similar structure. There are 209 different compounds in this group depending on the numbers of chlorines and the position of the chlorines attached to a "biphenyl" structure)



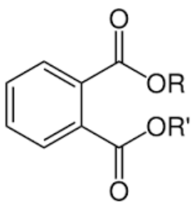
17-α ethynylestradiol (EE2)



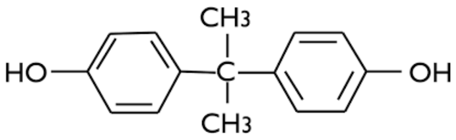
17-β estradiol (E2)



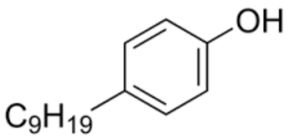
Phthalates (Thes are also a group of compounds. R and R' denote the organic functional groups attached to the common structure.)



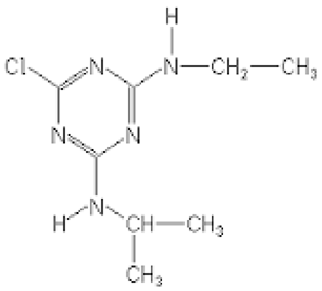
Bisphenol A



Nonylphenol



Atrazine



iii) List at least five different chemicals that can be classified as pharmaceuticals and personal care products (PPCPs) and briefly explain the uses of each chemical. (PPCPs로 분류될 수 있는 화합물을 최소 5가지 열거하고, 각 화합물의 용도를 간단히 설명하시오.)

Answer) Following are only several of many, many PPCPs. Note that PPCPs can be EDCs (or not).

caffeine: ingredients in coffee and soft drinks

ibuprofen: pain relieving / fever controlling drug

triclosan: soaps, shampoos, deodorants, and toothpastes

carbamazepine: mood-stabilizing drug

acetaminophen: pain relieving / fever controlling drug

codeine: analgesic

17-α ethynylestradiol: contraceptive pills

bisphenol A: plasticizer

triclocarbon: anti-microbial disinfectant

cotinine: nicotine metabolite

5. [Water quality] Bacterial cells can be represented by the chemical formula $C_5H_7O_2N$. Compute the theoretical oxygen demand (ThOD) of a bacterial suspension with a concentration of 100 mg/L. Assume the following reactions apply.

$$C_5H_7O_2N + 5O_2 \rightarrow 5CO_2 + 2H_2O + NH_3$$

$$NH_3 + 2O_2 \rightarrow NO_3^- + H^+ + H_2O$$

Answer) The formula weight of the bacterial cells ($C_5H_7O_2N$):

$$5\times12+1\times7+16\times2+14=113\ g/mol$$

The reactions show that 7 moles of oxygen molecules are consumed for one mole of bacterial cells.

The ThOD for a bacterial concentration of 100 mg/L is calculated as:

$$ThOD=\frac{(100\ mg\ bacterial\ cells/L)\times(10^{-3}g/mg)}{113\ g\ bacterial\ cells/mole\ bacterial\ cells}\times(7\ moles\ O_2/1\ mole\ bacterial\ cells)$$

$$\times(32\ g\ O_2/mole\ O_2)\times(10^3\ mg/g)$$

$$=198\ mg/L$$

6. [Water quality] You obtained following data from a BOD test:

Diluted wastewater:

Initial DO = 8.6 mg/L
Final DO (after 5 days) = 2.1 mg/L
Volume of wastewater = 2.5 mL
Total volume in BOD bottle = 300.0 mL

Seed control:

Initial DO = 8.6 mg/L
Final DO (after 5 days) = 7.3 mg/L
Volume of seeded dilution water = 300.0 mL

T = 20°C

Calculate the BOD_5 of the sample. Assuming that the ultimate BOD of the sample is 1000 mg/L, what is the BOD_7 of the sample?

Answer)

Calculating the dilution factor, P,

$$P=\frac{2.5\ mL}{300.0\ mL}=0.00833$$

Calculating the ratio of seed in diluted sample to seed in seed control, f,

$$f=\frac{297.5\ mL}{300.0\ mL}=0.992$$

The BOD_5 is calculated as follows:

$$BOD_5=\frac{(DO_{s,i}-DO_{s,t})-(DO_{b,i}-DO_{b,t})f}{P}$$

$$=\frac{(8.6\ mg/L-2.1\ mg/L)-(8.6\ mg/L-7.3\ mg/L)\cdot 0.992}{0.00883}$$

$$=590\ mg/L$$

Now, using $BOD_t=L_o(1-e^{-kt})$ *we can calculate the k value:*

$$BOD_5=590\ mg/L=(1000\ mg/L)\cdot[1-\exp(-k\cdot 5\ d)]$$

$$k = 0.178\ d^{-1}$$

$$BOD_7 = (1000\ mg/L) \cdot [1 - \exp(-0.178\ d^{-1} \cdot 7\ d)] = 712\ mg/L$$

7. [Water quality] The Audhumla town council has asked that you determine whether the discharge of the town's wastewater into the Einherjar River will reduce the DO below the state standard of 5.00 mg/L at Gotterdämmerung, 5.79 km downstream. Given the values in the table, what is the DO at Gotterdämmerung? What is the downstream distance from the town of Audhumla that will have the lowest DO? (The saturated DO concentration, DO_s at 28°C is 7.92 mg/L)

Parameter	Wastewater	Einherjar River
Flow (m^3/s)	0.280	0.877
Ultimate BOD	6.44	7.00
DO (mg/L)	1.00	6.00
k_d at 28°C (day^{-1})	-	0.199
k_r at 28°C (day^{-1})	-	0.370
Speed (m/s)	-	0.650
Temperature	28	28

Answer)

i) The oxygen deficit and ultimate BOD after mixing

$$D_a = DO_s - \frac{Q_w DO_w + Q_r DO_r}{Q_w + Q_r}$$

$$= 7.92\ mg/L - \frac{0.280\ m^3/s \cdot 1.00\ mg/L + 0.877\ m^3/s \cdot 6.00\ mg/L}{(0.280 + 0.877) m^3/s}$$

$$= 3.15\ mg/L$$

$$L_a = \frac{Q_w L_w + Q_r L_r}{Q_w + Q_r} = \frac{0.280\ m^3/s \cdot 6.44\ mg/L + 0.877\ m^3/s \cdot 7.00\ mg/L}{(0.280 + 0.877) m^3/s}$$

$$= 6.86\ mg/L$$

ii) Travel time from the town of Audhumla to Gotterdämmerung

$$t = \frac{5790\ m}{0.650\ m/s \cdot 86400\ s/day} = 0.103\ day$$

iii) The oxygen deficit at Gotterdämmerung

$$D_t = \frac{k_d L_a}{k_r - k_d}\left(e^{-k_d t} - e^{-k_r t}\right) + D_a\left(e^{-k_r t}\right)$$

$$= \frac{0.199\ day^{-1} \cdot 6.86\ mg/L}{0.370\ day^{-1} - 0.199\ day^{-1}}\left[\exp\left(-0.199\ day^{-1} \cdot 0.103\ day\right) - \exp\left(-0.370\ day^{-1} \cdot 0.103\ day\right)\right]$$

$$+ 3.15\ mg/L \cdot \exp\left(-0.370\ day^{-1} \cdot 0.103\ day\right)$$

$$= 3.17\ mg/L$$

iv) The DO at Gotterdämmerung

$$DO = 7.92\ mg/L - 3.17\ mg/L = 4.75\ mg/L$$

So, the DO at Gotterdämmerung is reduced below 5.00 mg/L.

v) The critical time, t_c

$$t_c = \frac{1}{k_r - k_d} ln\left[\frac{k_r}{k_d}\left(1 - D_a \frac{k_r - k_d}{k_d L_a}\right)\right]$$

$$= \frac{1}{0.370\ d^{-1} - 0.199\ d^{-1}} ln\left[\frac{0.370\ d^{-1}}{0.199\ d^{-1}}\left(1 - 3.15\ mg/L \cdot \frac{0.370\ d^{-1} - 0.199\ d^{-1}}{0.199\ d^{-1} \cdot 6.86\ mg/L}\right)\right]$$

$$= 0.692\ d$$

vi) The distance having the lowest DO, L_c

$$L_c = t_c \times v_{river} = 0.692\ day \times 0.650\ m/s \times 86400\ s/day \times 10^{-3}\ km/m = 38.9\ km$$