(18)

B. Sc. in Civil Engineering
8th Semester

Date: 15th May, 2023
Time: 10:00 AM–1:00 PM

ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)

ORGANISATION OF ISLAMIC COOPERATION (OIC)

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Final Examination
Course Number: CEE 4835
Course Title: Environmental Modeling

Summer Semester: 2021–2022
Full Marks: 150
Time: 3 Hours

There are **7 (seven)** questions. You can answer **any 6 (six)** questions. Marks of each question and corresponding CO and PO are written in the brackets. The figures in the right margin indicate marks. The symbols have their usual meanings.

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(1) a) Figure 1 shows a river that receives wastewater from an effluent treatment plant at kilometer point 0 (KP 0) and a tributary inflow at KP 30. For 60 km downstream from the treatment plant, there is a BOD settling removal rate of 0.25 d^{-1}. If the stream is at sea level, compute the following at KP '0' and '30' –

i. the concentration of BOD [5] CO3 PO2

ii. the oxygen saturation [5] CO3 PO2

iii. the amount of oxygen deficit [5] CO3 PO2

iv. the concentration of dissolved oxygen [5] CO3 PO2

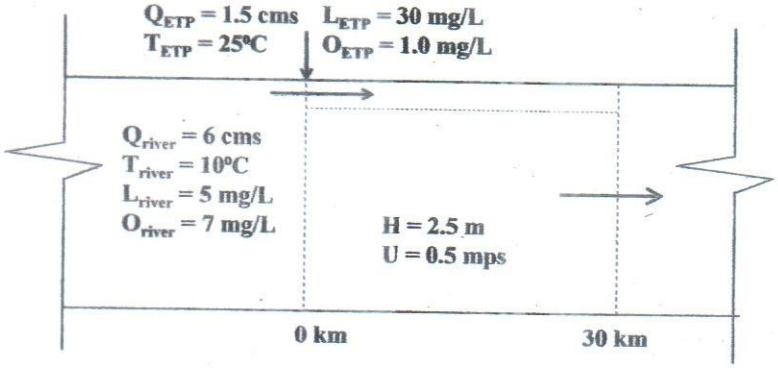

Figure 1

Necessary details are provided in Appendix for Question 1.

b) Sketch the plot of BOD downstream from a point source of untreated sewage into a river. Show the cases for both – deep and shallow stream. [5] CO1 PO1

(2) a) A point source Gaussian Plume Model for a power plant emitting CO has an effective stack height as 50 m (Figure 2). The night is overcast with surface wind speed stays at 1.5 m s^{-1}. Your concern is with ground level pollution at two locations, A and B, which are 1.2 and 1.4 km directly downwind from the stack.

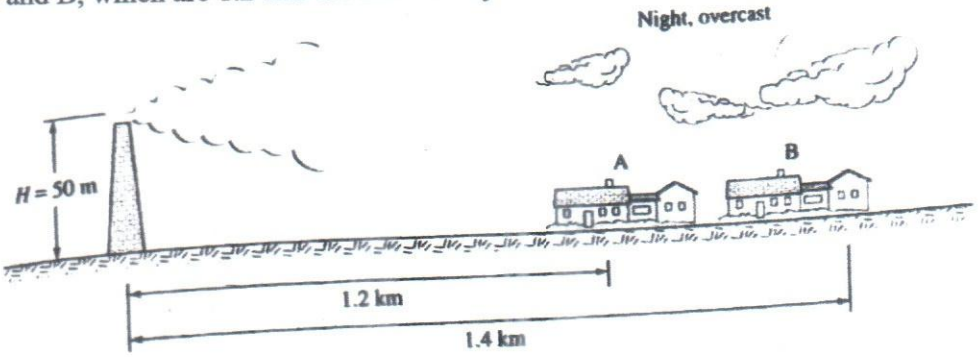

Figure 2

i. At what distance will the maximum concentration of pollution occur? Which location (A or B) would have the higher level of pollution? [2.5] CO3 PO2

ii. Suppose the sky clears up and the windspeed stays at 5 m s^{-1}. Will the location downwind at which the maximum concentration occurs move? If so, will it move closer to the stack or further way from the stack? Which house would experience the most pollution? (H remains as 50 m) [2.5] CO3 PO2

Necessary details are provided in Appendix for Question 2.

b) Suppose a bonfire emits CO at the rate of 15 g s^{-1} on a clear night when the wind is blowing at 1.5 m s^{-1}. If the effective stack height at the fire is 8 m, (i) what would you expect the ground level CO concentration to be at 450 m directly downwind? (ii) Estimate the maximum ground level concentration. Refer to Appendix for Question 2 for additional information. [7.5] CO3 PO2

c) A stack emits 900 g s^{-1} gas the molecular weight of which is 28 g. Maximum NO in the exhaust gas is 50 ppm. The stack has an effective height of 80 m. The windspeed is 3 m s^{-1} at 10 m height. It is a clear summer day with sun nearly overhead. Estimate the NO concentration at a point located 5 km downwind and 0.1 km off the downwind axis. [7.5] CO3 PO2

d) Explain three major atmospheric stability classes with respect to environmental and adiabatic lapse rate. [5] CO1 PO1

(3) a) A well serving an industry pumps at 1.5 m^3 s^{-1} suddenly discovers hydrocarbon possibly from gasoline in the waste water and filed a lawsuit against every gas station within a 2.5 km radius. Station A is 1700 m North and 600 m West; station B is 100 m south; and station C is 100 m north and 500 m west. Hydrogeologists determine that the phreatic aquifer is in an infinite flow domain, is 10 m thick, has hydraulic conductivity of 0.025 m s^{-1} and has a regional hydraulic gradient of 0.005 from north to south. In this circumstance, which of the lawyers will have a difficult time defending his client (Figure 3 is provided for your reference)? Justify your answer. [7.5] CO3 PO2

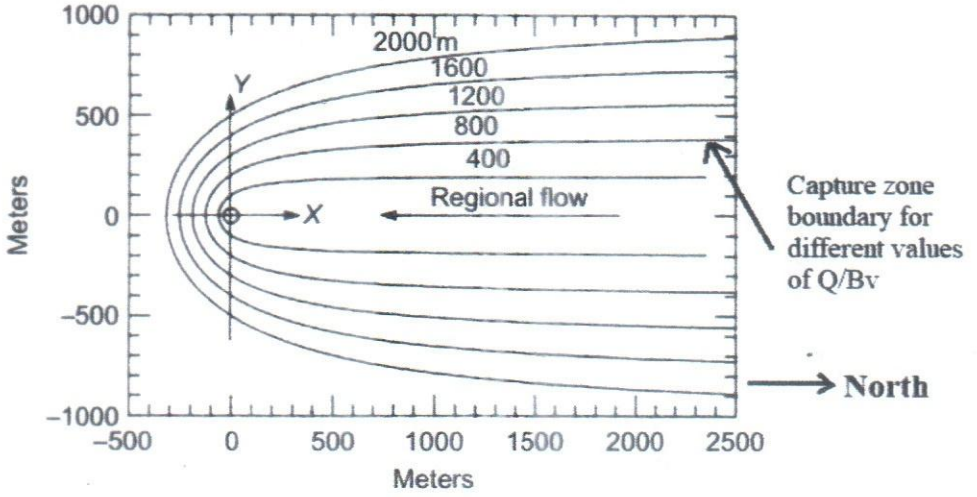

Figure 3

b) In 2020, gasoline contamination was discovered during a routine site assessment at an urban site shown in Figure 4. It is not known how long before 2020 this contamination reached the site, assuming that it originated off-site. At the site, hydraulic conductivity is 100 ft day^{-1}, porosity is 0.3, gradient (in direction indicated) is 0.00225, and transverse dispersivity is 8 ft. Make a justified recommendation as to which gas station or stations are the likely culprits (include all assumptions): Station A was established in 2008; Station B in 2016; and Station C in 2014. [7.5] CO3 PO2

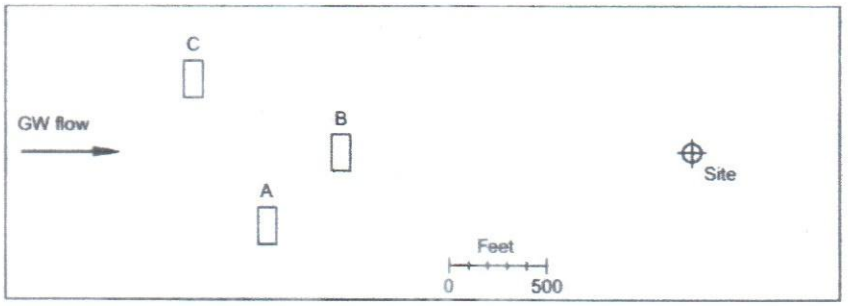

Figure 4

c) In a sand having a median grain size of 0.1 mm and porosity of 0.25, such as might be used to pack a column for a lab-scale experiment, how high must seepage velocity be to make the mechanical dispersion coefficient equal to the effective molecular diffusion coefficient? [5] CO3 PO2

d) Why is longitudinal dispersion stronger than transverse dispersion in case of pollutant transport in groundwater? [5] CO1 PO1

4) a) You place 2 mg of glucose in a 250-ml bottle. After adding a small quantity of bacteria, you fill the remainder of the volume with water and stopper the bottle. The initial concentration of oxygen is 10 mg L^{-1}. If glucose decomposes at a rate of 0.1 d^{-1}, determine the oxygen concentration in this closed batch system. [10] CO3 PO2

b) Determine the saturation for an estuary with a temperature of 20°C and a salinity of 25 ppt. Also determine the percentage of saturation oxygen in the saltwater compared to the freshwater. [10] CO3 PO2

c) Explain the dissolved oxygen sag curve that occurs below sewage discharges into streams. [5] CO1 PO1

(5) a) A pollutant particle is flowing through a 10 m long circular pipe with a radius of 16 cm. The concentration of that pollutant at the end of the pipe are 30 kg m^{-3} and 10 kg m^3. The diffusion constant for that pollutant particle at 20°C is 1.8×10^{-5} m^2s^{-1}.
i) Calculate the diffusion flow rate.
ii) How many kg of that pollutant will flow through this pipe in 15 minutes?
iii) Calculate the concentration gradient.
iv) What is the concentration of that pollutant 2 m away from the end of the pipe at high concentration?
v) How long will it take for 100 kg of that pollutant to travel through the pipe? [10] CO3 PO2

b) A tall stack and a nearby short stack have plumes as shown in Figure 5. Which atmospheric temperature profile would be most likely to cause that pair of plumes? The solid and dotted line represent the environmental and dry adiabatic lapse rate, respectively. Justify your answer. [2.5] CO3 PO2

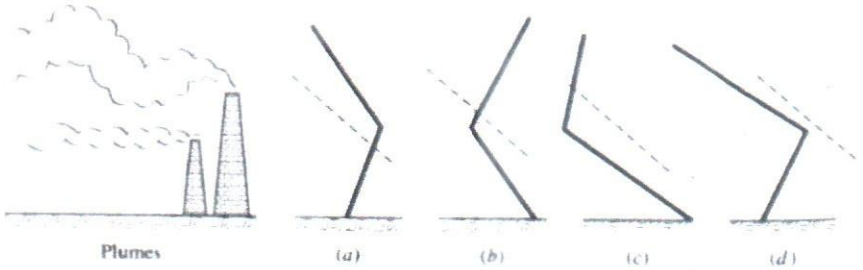

Figure 5

c) A powerplant stands 150 m high and has an inner diameter at the top as 1.5 m. Emission gas exit the stack at 120 °C at 12 m s^{-1} while the ambient temperature is 8°C. Wind speed at stack height is 5 m s^{-1}. It is a clear summer day with sun higher than 60° above the horizon and surface wind speed of 5 m s^{-1}, estimate the effective stack height of the powerplant. Refer to Appendix for Question 5 for necessary details. [7.5] CO3 P

d) Define temperature inversion and mixing depth. [5] CO1 P

(6) a) Copper-rich waste disposed of in lagoons behind an electroplating operation has percolated down to the groundwater and dissolved, creating a plume. A sample of the porous medium and associated pore water is taken from the plume area and analyzed, The results are – [10] CO3 P

Cu conc. in pore water = 10^{-6} mol $liter^{-1}$,
Cu conc. in aquifer solids = 10^{-3} mol kg^{-1},
aquifer bulk density of 2.5 g cm^{-3},
aquifer porosity = 0.3
If groundwater seepage velocity is 600 ft $year^{-1}$, how fast will the plume migrate?

b) For an aquifer solid with a bulk density of 2g cm^{-3} containing 0.5% organic carbon, estimate the retardation factor for napthalene. If the porosity of the aquifer is 0.24, the hydraulic conductivity is 10^{-3} cm sec^{-1} and the hydraulic gradient is 0.001, how fast the plume of napthalene will travel? Given, log(Koc) = 3.146. [10] CO3 P

c) What is NAPL and DNAPL? Why DNAPL removal is more difficult than NAPL removal? [5] CO1 P

(7) a) Use the cascade model to simulate the steady-state distribution of concentration in an elongated tank shown in Figure 6. The tank has cross-sectional area A_c = 20 m^2, length L = 100 m, velocity U = 100 m hr^{-1}, and first-order reaction rate k = 2 hr^{-1}. The inflow concentration is 1 mg L^{-1}. Use n = 1, 2 and 3 CSTRs to approximate the concentration in tank. Plot and comment on the results. [10] CO3 P

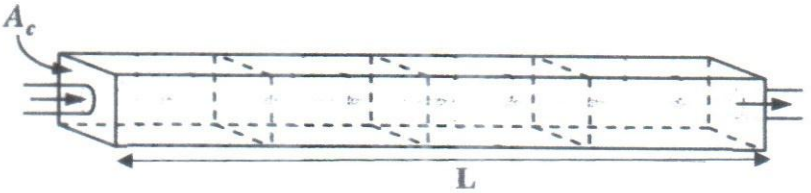

Figure 6

b) Suppose that three lakes (Lake 1 → Lake 2 → Lake 3) connected in series have the following characteristics: [10] CO3 P

Parameters	Units	Lake 1	Lake 2	Lake 3
Loading	kg yr^{-1}	2,000	4,000	1,000
Mean Depth	m	3	7	3
Surface Area	10^6 m^2	0.667	0.571	1.000
Volume	10^6 m^3	2	4	3
Outflow	10^6 m^3 yr^{-1}	1.0	1.0	1.0

If the pollutant settles at a rate of 10 m yr^{-1} and concentration in Lake 1 is 260.76 $\mu g\ L^{-1}$,

i. Calculate the steady-state concentration in Lake 2.

ii. Determine the concentration in Lake 3 due to the loading of the Lake 2.

c) Describe the two general ways in which completely mixed reactors can be connected. [5] CO1 PO1

Appendix for Question 1

$$k_d = 0.3\left(\frac{H}{2.4}\right)^{-0.434} \qquad 0 \le H \le 2.4 \text{ m}$$

$$k_d = 0.3 \qquad H > 2.4 \text{ m}$$

$$\boxed{k_a = 3.93\frac{U^{0.5}}{H^{1.5}}}$$

Units: $k_a(\text{d}^{-1})$, $U(\text{mps})$, $H(\text{m})$

$$\ln o_{sf} = -139.34411 + \frac{1.575701 \times 10^5}{T_a} - \frac{6.642308 \times 10^7}{T_a^2} + \frac{1.243800 \times 10^{10}}{T_a^3} - \frac{8.621949 \times 10^{11}}{T_a^4}$$

Appendix for Question 2

TABLE ATMOSPHERIC STABILITY CLASSIFICATIONS

Surface wind speed[a] (m/s)	Day solar insolation			Night cloudiness[e]	
	Strong[b]	Moderate[c]	Slight[d]	Cloudy (≥4/8)	Clear (≤3/8)
<2	A	A–B[f]	B	E	F
2–3	A–B	B	C	E	F
3–5	B	B–C	C	D	E
5–6	C	C–D	D	D	D
>6	C	D	D	D	D

[a]Surface wind speed is measured at 10 m above the ground

[b]Corresponds to clear summer day with sun higher than 60° above the horizon

[c]Corresponds to a summer day with a few broken clouds, of a clear day with sun 35-60° above horizon

[d]Corresponds to a fall afternoon, or a cloudy summer day, or a clear summer day with sun 15-35° above horizon

[e]Cloudiness is defined as the fraction of sky covered by clouds

[f] For A-B, B-C, or C-D conditions, average the values obtained for each

$$C(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left[-\frac{y^2}{2\sigma_y^2}\right]\left\{\exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right]\right.$$
$$+ \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z-H-2hm)^2}{2\sigma_z^2}\right]$$
$$+ \exp\left[-\frac{(z-H+2hm)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H-2hm)^2}{2\sigma_z^2}\right]$$
$$\left. + \exp\left[-\frac{(z+H+2hm)^2}{2\sigma_z^2}\right]\right\}$$

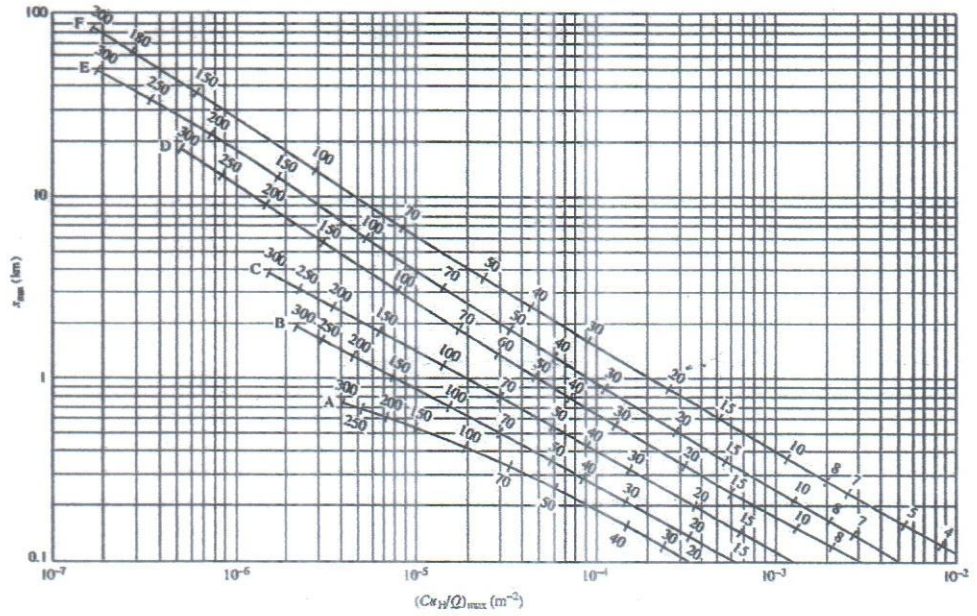

TABLE VALUES OF THE CONSTANTS, *a*, *c*, *d*, AND *f* FOR USE IN (7.32) AND (7.33)[a]

		$x \leq 1$ km			$x \geq 1$ km		
Stability	*a*	*c*	*d*	*f*	*c*	*d*	*f*
A	213	440.8	1.941	9.27	459.7	2.094	−9.6
B	156	106.6	1.149	3.3	108.2	1.098	2.0
C	104	61.0	0.911	0	61.0	0.911	0
D	68	33.2	0.725	−1.7	44.5	0.516	−13.0
E	50.5	22.8	0.678	−1.3	55.4	0.305	−34.0
F	34	14.35	0.740	−0.35	62.6	0.180	−48.6

[a] The computed values of σ will be in meters when x is given in kilometers.

$\sigma_y = a.x^{0.894}$

$\sigma_z = c.x^d + f$

TABLE WIND PROFILE EXPONENT p FOR ROUGH TERRAIN[a]

Stability class	Description	Exponent, p
A	Very unstable	0.15
B	Moderately unstable	0.15
C	Slightly unstable	0.20
D	Neutral	0.25
E	Slightly stable	0.40
F	Stable	0.60

[a] For smooth terrain, multiply p by 0.6; see Table 7.8 for further descriptions of the stability classifications used here.

Appendix for Question 4

$$\ln o_{ss} = \ln o_{sf} - S\left(1.7674 \times 10^{-2} - \frac{1.0754 \times 10^{1}}{T_a} + \frac{2.1407 \times 10^{3}}{T_a^2}\right)$$

$$S = 1.80655 \times \text{Chlor}$$

$$o_{sp} = o_{s1}[1 - 0.1148 \times \text{elev(km)}]$$

$$o_{sp} = o_{s1}[1 - 0.000035 \times \text{elev(ft)}]$$

Appendix for Question 5

$$F = g\, r^2\, v_s\, (1 - T_a/T_s)$$

$$\Delta h = (1.6\, F^{1/3}\, x_f^{2/3})/u$$

$$x_f = 120\, F^{0.4}, \quad F \geq 55\ m^4/s^3$$

$$x_f = 50\, F^{5/8}, \quad F < 55\ m^4/s^3$$

$$\Delta h = 2.6\, (\frac{F}{uS})^{1/3}$$

$$S = \frac{g}{Ta}\,(\frac{\Delta Ta}{\Delta z} + \Gamma)$$