SULIT

Second Semester Examination
2020/2021 Academic Session

July 2021

KAT442 Environmental Pollution Chemistry

Duration: 2 hours

Please check that this examination paper consists of **Thirteen (13)** pages of printed material before you begin the examination.

Instructions:

This paper has **FIVE (5)** questions in **SECTIONS A** and **B**. Answer all **THREE (3)** questions from **SECTION A** and **ONE (1)** question from **SECTION B**.

Answer each question on a new page.

If a candidate answers more than four questions, only the answers to the first four questions in the answer sheet will be graded.

Appendix: Some related formula

SECTION A

1. (a) Rain samples for an industrial area are analysed monthly and believed to contain corrosive elements, H_2SO_4 and HNO_3. In detail mechanisms, show how these elements exist.

(6 marks)

(b) A power plant releases a grey smog plume that contains a high concentration of sulphur dioxide into the atmosphere around 8 am. The plume spread out horizontally but do not mix vertically. From the observation, the plume does not reach the ground level and extend downwind from the source for long-distance.

(i) Using an illustration, predict the type of plume produced.

(ii) Explain the factor that contributes to the formation of this plume.

(7 marks)

(c) A rising plume of stack gas has a temperature of 1000 °C at 200 m. Assuming an adiabatic lapse rate, determine the temperature at 1000 m.

(4 marks)

(d) Estimate the rate of emission of SO_2 in g s^{-1} that results in a centreline (y = 0) concentration at the ground level of 1.412×10^{-3} g m^{-3} one kilometre from the stack. The time of the measurement was 1 pm on a clear summer afternoon. The wind speed was 1.8 m s^{-1} measured at the height of 10 m. The effective stack height is 94 m. No inversion is present.

(8 marks)

2. (a) Phosphorus is a chemical element that has been classified as nutrient and also as aquatic pollutant. Discuss its sources in the aquatic environment with relevant examples.

(4 marks)

(b) A stream flows into a lake at a flowrate of 0.2 m^3 s^{-1} containing phosphate at a concentration of 10 mg L^{-1}. However, it was found that the effluent that flows out of the lake contains 5 mg L^{-1} phosphate.

(i) Discuss FOUR (4) possibilities of the fate of phosphorus in the lake.

(ii) Explain the main problem that could be faced by the lake due to this uptake of the phosphate.

(10 marks)

(c) With the aid of a figure, discuss how you would expect pE to vary with depth in a stratified lake.

(6 marks)

(d) Discuss how the data obtained from chemical oxygen demand and biochemical oxygen demand can be used to determine the level of pollution in a lake.

(5 marks)

3. (a) Methylmercury accumulates biologically in living organism due to its relatively good solubility in fat and muscle tissues.

(i) Estimate the depuration rate, b, if the lifetime of mercury is 70 days.

(ii) If the lowest level of methyl mercury in the brain is 5 mg g^{-1} and average size of the brain is 1.6 kg, while 10% of mercury load inside human body is stored inside the brain, predict the maximum value of mercury intake by human to maintain steady state condition within the human body.

(6 marks)

(b) Water quality index (WQI) is introduced to indicate the degree of pollution of a water body without invoking all the values of water quality parameters. Malaysian Department of Environment (DOE, 2001) provides a guideline for the determination of WQI, which involve monitoring of six parameters (pH, DO, BOD, COD, AN, and TSS). A study of Lake Chini in May 2005 provides the following results.

Parameter	Results	Parameter	Results
Temp (ºC)	31	**COD (mg L^{-1})**	22.76
DO (mg L^{-1})	6.54	**AN (mg L^{-1})**	0.117
pH	6.61	**TSS (mg L^{-1})**	6.87
BOD (mg L^{-1})	1.89		

Based on the table above,

(i) determine the WQI value for Lake Chini in May 2005.

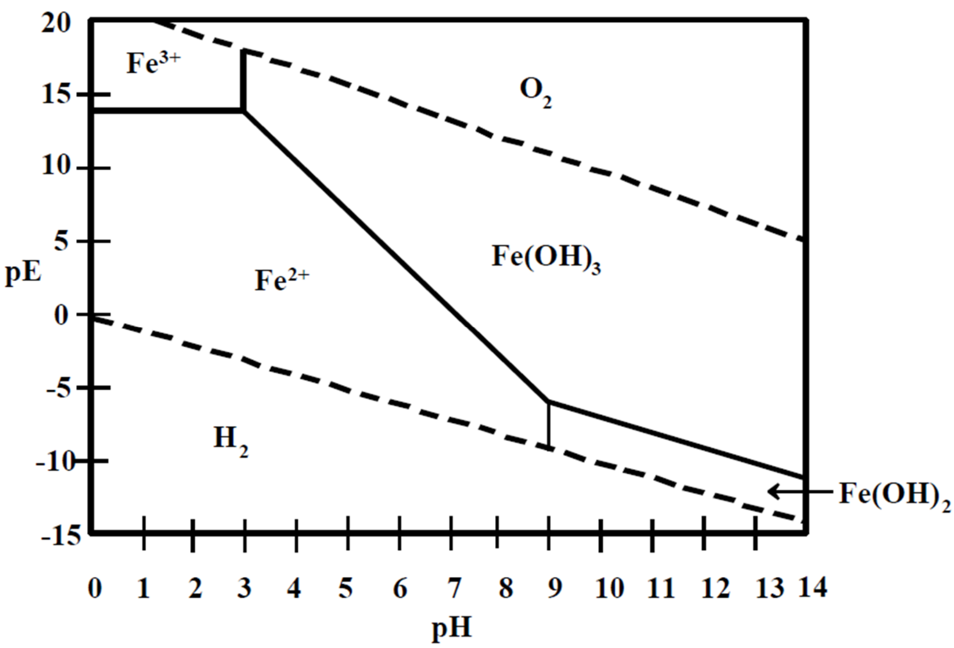
(ii) comment on the pollution condition of the lake.

(9 marks)

(c) The following pE–pH diagram describes the distribution of iron species in aquatic environment. If the maximum concentration of iron in water is 1.00 x 10^{-5} M,

(i) determine the pE° value for the equilibrium of Fe^{2+} and Fe^{3+}. Given the E°= 0.77 V.

(ii) prove that precipitation of $Fe(OH)_3$ occurs at pH 2.99 without the influence of pE. The K_{sp} for $Fe(OH)_3$ is 9.1 x 10^3.



(6 marks)

(d) A river receives wastewater flow with an ultimate BOD value L_o, after mixing. Measurement of the DO value at critical areas gives a maximum deficit, D_m, with value of 4 mg L^{-1}. Assume that there are no changes occurring in the k_i (deoxygenation constant) and k_2 (re-aeration constant) values. If the initial deficit, D_o, for the river water is 0 and the value of saturated dissolved oxygen is 10.0 mg L^{-1}, determine the value of critical DO when the ultimate BOD after mixing becomes double in value.

(4 marks)

SECTION B

4. (a) Polar stratospheric clouds (PSCs) are clouds in the winter polar stratosphere at altitudes of 15,000–25,000 m (49,000–82,000 ft). PSCs are made up mostly of supercooled droplets of water and nitric acid and is implicated in the depletion of ozone. Illustrate the role of PSCs in ozone depletion.

(5 marks)

(b) Air pollution dispersion refer to the distribution of air pollution into the atmosphere. It explains what happens to the pollution during and after its introduction. Understanding this may help in identifying and controlling air pollutants.

(i) Discuss the prime mechanism of air pollution dispersion.

(ii) Predict what happens to air pollutants during a temperature inversion.

(7 marks)

(c) The National Ambient Air Quality Standard for ozone is 0.08 ppmv measured over an eight-hour averaging time. Determine the equivalent concentration in μg m^{-3} at 1 atm of pressure and 25 °C.

(3 marks)

(d) On a summer afternoon with a wind speed of 3.20 m s^{-1}, the concentration of particulate matter was found to be 1520 μg m^{-3} at a point 2 km downwind and 0.5 km perpendicular to the plume centreline from a coal-fired power plant. Estimate the particulate emission rate of the power plant, given the following:

Stack Parameters	Atmospheric Condition
Height: 75.0 m	Pressure: 100 kPa
Diameter: 1.50 m	Temperature: 28 °C
Exit velocity: 12 m s^{-1}	
Temperature: 322 °C	

(10 marks)

5. (a) About 5 mL of a lake water sample was diluted with 100 mL of distilled water. Ammonia content of the sample was analysed using the Nessler method. The developed colour was then measured using a spectrophotometer. The following table provides the results of the measurement.

Solution (mg L^{-1})	**% Absorbance**
0	0
1	6
2	12
3	18
Sample	15

(i) List the chemical equations of the reactions that occur during the nesslerisation process.

(ii) Calculate the amount of ammonia in the water sample.

(iii) Discuss the possible implication that can happen to the aquatic environment of the lake based on the observed concentration of ammoniacal nitrogen.

(iv) Determine TWO (2) control methods to remove ammoniacal nitrogen from water.

(13 marks)

(b) In general, water may contain various soluble species which can react with Fe through various reactions. If it was found that water contains carbonate anion, predict the value of the boundary line for Fe^{2+} – $FeCO_3$ couple. Assume that the equilibrium concentrations of Fe^{3+} and CO_3^{2-} are 10^{-3} M and 10^{-2} M, respectively, and the following data are known:

$$FeCO_3 + H^+ \leftrightarrow Fe^{2+} + HCO_3^-; \qquad K_{sp} = 3.5 \times 10^{-11}$$

$$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}; \qquad K_{a2} = 4.69 \times 10^{-11}$$

(12 marks)

APPENDIX

Some Related Formulas

Holland's equation:

$$\Delta h = \frac{V_s D}{u}\left[1.5 + \left(0.0268PD\left(\frac{T_s - T_a}{T_s}\right)\right)\right]$$

Gaussian dispersion equation:

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

Relative atomic mass (RAM)
S = 32.07
O = 16.00

Table 1: Stability class categories

Surface Wind Speed[a] ms^{-1}	Day Incoming Solar Radiation			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, or a clear day with sun 35-60° above the horizon.
[d]Corresponds to a fall afternoon, or a cloudy summer day, or a clear summer day with sun 15-35°.
[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.
*A = Very unstable D = Neutral
B = Moderately unstable E = Slightly stable
C = Slightly unstable F = Stable
Regardless of wind speed, Class D should be assumed for overcast conditions, day or night.

Table 2: Power law exponents for wind profile calculations

Exponent *p* values for rural and urban regimes					
Stability class	**Rural**	**Urban**	**Stability class**	**Rural**	**Urban**
A	0.07	0.15	D	0.15	0.25
B	0.07	0.15	E	0.35	0.30
C	0.10	0.20	F	0.55	0.30

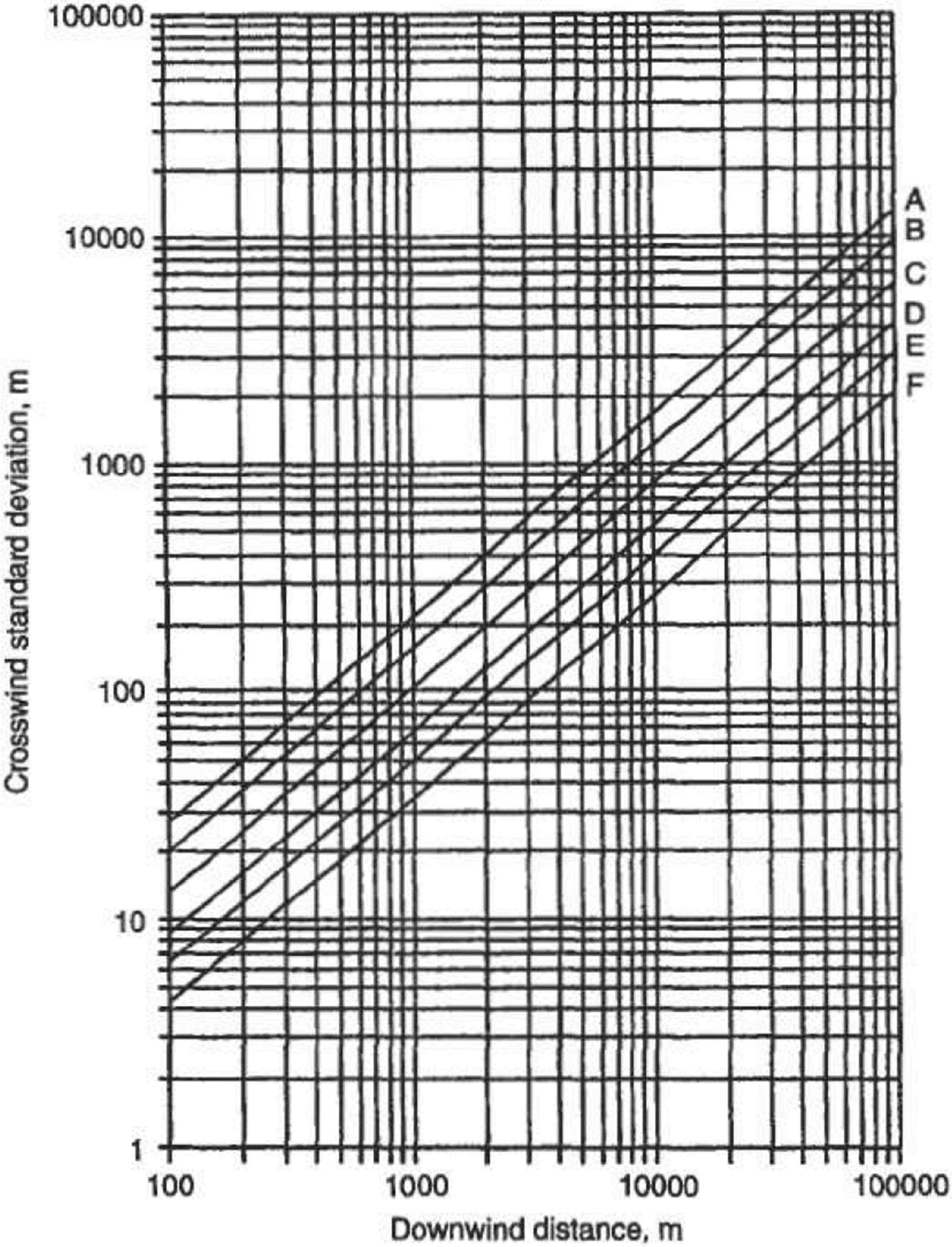


Figure 1: Horizontal dispersion coefficient σ_y

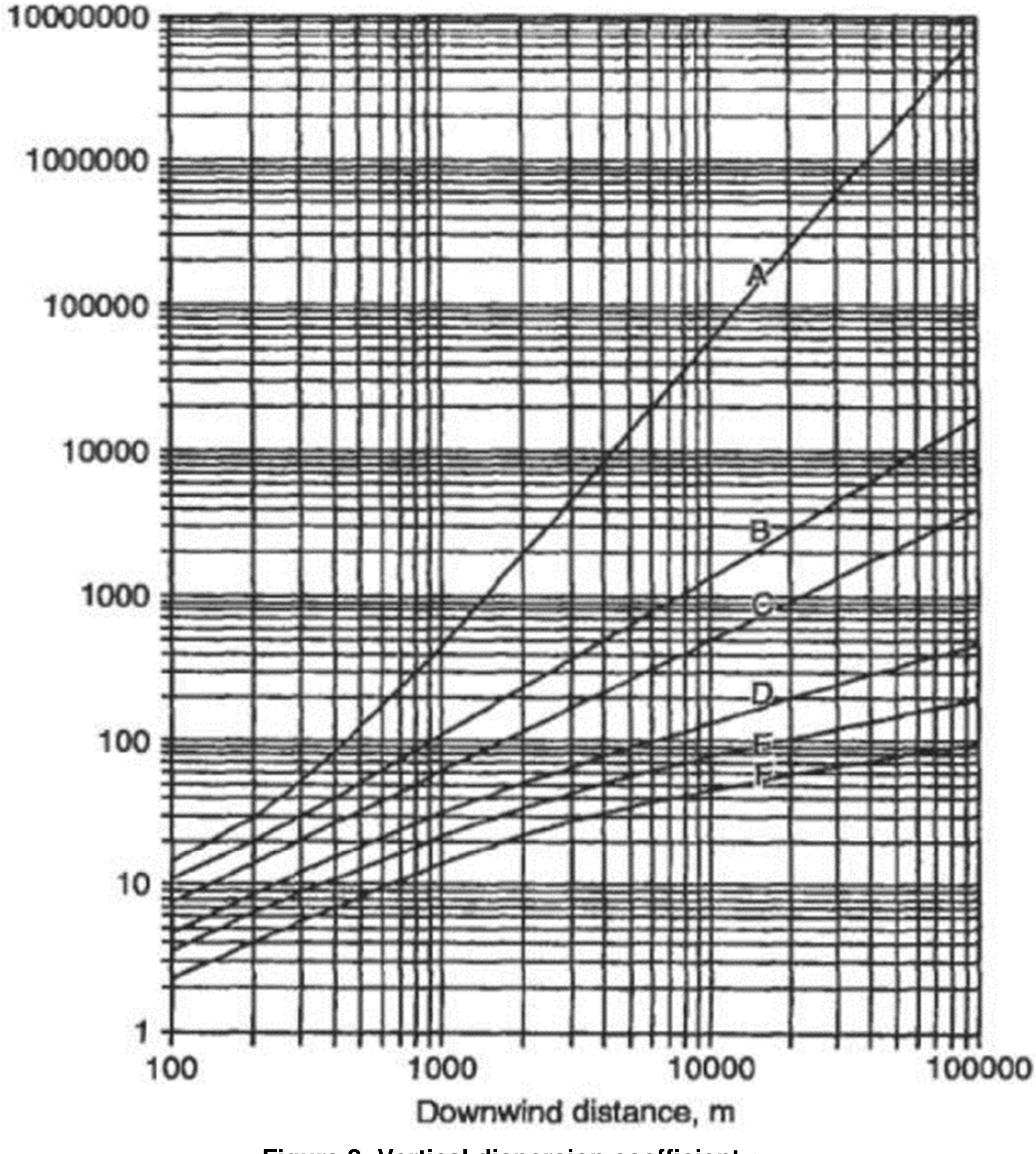


Figure 2: Vertical dispersion coefficient σ_z

Table 3: Constant for calculating dispersion coefficient

Stability Category	a	Distance downwind (km) x ≤ 1 km			Distance downwind (km) x ≥ 1 km		
		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

List of abbreviations

Abbreviations	**Expanded Names**
AN	Ammoniacal Nitrogen
BOD	BiochemicaL Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
TDS	Total Dissolved Solid
TOC	Total organic carbon
TSS	Total Suspended solid

Dilution table for BOD analysis

Direct Measurement		**Premixing (Volume of Wastewater to total volume)**	
Wastewater (mL)	**BOD range (mg L^{-1})**	**Percent Mixing**	**BOD range (mg L^{-1})**
0.20	3000 – 10,500	0.10	2000 – 7000
0.50	1200 – 4200	0.20	1000 – 3500
1.0	600 – 2100	0.50	400 – 1400
2.0	300 – 1050	1.0	200 – 700
5.0	120 – 420	2.0	100 – 350
10.0	6 – 210	5.0	40 – 140
20.0	30 – 105	10.0	20- 70
50.0	12 – 42	20.0	10 – 35
100	6 – 21	50.0	4 – 14

WQI FORMULA AND CALCULATION

FORMULA

WQI = (0.22 * SIDO) + (0.19 * SIBOD) + (0.16 * SICOD) + (0.15 * SIAN) + (0.16 * SISS) + (0.12 * SIpH)
where;
SIDO = Subindex DO (% saturation)
SIBOD = Subindex BOD
SICOD = Subindex COD
SIAN = Subindex NH_3-N
SISS = Subindex SS
SIpH = Subindex pH
$0 \le WQI \le 100$

BEST FIT EQUATIONS FOR THE ESTIMATION OF VARIOUS SUBINDEX VALUES

Subindex for DO (in % saturation)

SIDO = 0	for $x \le 8$
SIDO = 100	for $x \ge 92$
SIDO = $-0.395 + 0.030x^2 - 0.00020x^3$	for $8 < x < 92$

Subindex for BOD

SIBOD = $100.4 - 4.23x$	for $x \le 5$
SIBOD = $108 * \exp(-0.055x) - 0.1x$	for $x > 5$

Subindex for COD

SICOD = $-1.33x + 99.1$	for $x \le 20$
SICOD = $103 * \exp(-0.0157x) - 0.04x$	for $x > 20$

Subindex for NH_3-N

SIAN = $100.5 - 105x$	for $x \le 0.3$
SIAN = $94 * \exp(-0.573x) - 5 * \lvert x - 2 \rvert$	for $0.3 < x < 4$
SIAN = 0	for $x \ge 4$

Subindex for SS

SISS = $97.5 * \exp(-0.00676x) + 0.05x$	for $x \le 100$
SISS = $71 * \exp(-0.0061x) - 0.015x$	for $100 < x < 1000$
SISS = 0	for $x \ge 1000$

Subindex for pH

SIpH = $17.2 - 17.2x + 5.02x^2$	for $x < 5.5$
SIpH = $-242 + 95.5x - 6.67x^2$	for $5.5 \le x < 7$
SIpH = $-181 + 82.4x - 6.05x^2$	for $7 \le x < 8.75$
SIpH = $536 - 77.0x + 2.76x^2$	for $x \ge 8.75$

A table for saturated DO values for water of different temperatured

Temp (°C)	DO (mg L^{-1})
18	9.5
19	9.4
20	9.2
21	9.0
22	8.8
23	8.7
24	8.5
25	8.4
26	8.2
27	8.1
28	7.9
29	7.8
30	7.6

Useful Equations

$$\text{Log } r = \log(L_oK) - K_{10}t$$

$$L_t = L_oe^{-kt}$$

$$D_t = \frac{K_1L_o}{K_2 - K_1}\left(e^{-K_1t} - e^{-K_2t}\right) + D_0e^{-K_2t}$$

$$t_c = \left[\frac{1}{K_2 - K_1}\right]\text{In}\left[\frac{K_2}{K_1}\left(1 - D_o\frac{K_2 - K_1}{L_oK_1}\right)\right]$$

$$C = \frac{C_1 \text{ x } Q_1 + C_2 \text{ x } Q_2}{Q_1 + Q_2}$$

$$K_2 = 3.9\frac{v^{1/2}}{H^{3/2}}$$

$$K_T = K_{20} \text{ x } 1.047^{T-20}$$

$$K_T = K_{20} \text{ x } 1.022^{T-20}$$

$$BOD = \frac{(D_1 - D_2)}{P}$$

$$BOD = \frac{(D_1 - D_2) - (B_1 - B_2)f}{P}$$

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