Exam Water Quality

Master Civil Engineering and Management

Course code:	201800023
Date:	October 29, 2018
Location:	Sportcentrum Hal 1
Time:	13:45-16:45 *(17:30 for students with right of extra time (25%))*
Lecturer:	D.C.M. Augustijn

Type exam: Closed book

Appendix: Information sheet Water Quality

Instructions:

- This exam consists of three parts: 10 true/false questions, 5 multiple choice questions (with four options of which only one is correct) and 4 open questions. The true/false questions each value 1 point, multiple choice questions each value 2 points, and the open questions value at total of 25 points (the number of points are indicated per subquestion). A partly correct answer to an open question is awarded part of the allocated points.
- Write the answers on the provided answer sheets. Write your name on each separate sheet. The blank pages in the middle can be used as scrap paper.
- This is a closed book exam, so you are not allowed to use any books or notes, except the information sheet which is handed out at the beginning of the exam.
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- You have 3 hours for the entire exam. Plan your exam well.
- You may use dictionaries (no digital versions).
- You may use a (graphical) calculator.
- Answer the questions in English (language errors are not lowering your grade).
- In answering the questions, be concise and clear.
- Hand in all papers (answer sheet(s), information sheet and these questions; you may keep the scrap paper).

Good Luck!

Section 1: True/False *(10 points)*

Indicate for each of the following statements whether the statement is **True** or **False**:

1. According to the EU water framework directive (WFD) a good chemical status is achieved when for all priority pollutants the concentration is below the water quality standard. TRUE [90%]
2. Wooden bank protection is a serious source of polyaromatic hydrocarbons (PAHs) in water. TRUE [100%]
3. Hydrophobic organic pollutants adsorb mainly to clay surfaces. FALSE (hydrophobic organic pollutants adsorb mainly to natural organic matter) [76%]
4. Diatoms are covalent bonds between two atoms like O_2, H_2, etc. FALSE (diatoms are algae species with a silicon skeleton) [52%]
5. Primary production is the term for the production of biomass by algae through the assimilation of carbon dioxide. TRUE [67%]
6. The Michaelis-Menten or Monod kinetics are commonly used to describe the nonequilbrium process of volatilization. FALSE (the Michaelis-Menten or Monod kinetics are commonly used to describe the growth of algae) [86%]
7. Detritus is an important source of nutrients in water bodies. TRUE [71%]
8. Dispersion of pollutants in rivers is mainly driven by a concentration gradient. FALSE (dispersion is caused by local velocity differences) [57%]
9. QSARs (quantitative structure-activity relationships) can be used to estimate toxicity characteristics of pollutants for which little information is available. TRUE [71%]
10. The application of UV or ozone in the third stage of water treatment is meant to further reduce the nutrient concentrations. FALSE (UV or ozone can be used to remove pathogenic bacteria) [71%]

Section 2: Multiple-choice questions *(10 points)*

Question 11: Dicalciumphosphate $CaHPO_4$ (M = 136 g/mol) is an artificial fertilizer that is often used by farmers to supply phosphate to the soil to support crop growth. $CaHPO_4$ dissolves in water according to the following reaction:

$$CaHPO_4\,(s) \rightleftarrows Ca^{2+} + HPO_4^{2-} \qquad K = 2.5\cdot10^{-7}$$

If 10 gram of $CaHPO_4$ per m^2 is applied to the soil as solid granules, how much rainfall is at least required to dissolve all $CaHPO_4$?

A. < 100 mm
B. between 100 and 500 mm
C. between 500 and 1000 mm
D. > 1000 mm

When x mol of $CaHPO_4$ dissolves this leads to x mol Ca^{2+} and x mol HPO_4^{2-}. So $K = [Ca^{2+}][HPO_4^{2-}] = x\cdot x = x^2 = 2.5\cdot10^{-7} \rightarrow x = 0.0005$ mol/l
So 0.0005 mol $CaHPO_4$ can dissolve in 1 liter. This is $0.0005\cdot136 = 0.068$ gram per 1 liter. To dissolve 10 g this requires at least 147 liter. 100 mm = 0.1 m x 1 m^2 = 0.1 m^3 = 100 liter, hence 147 mm is required.

Correct answer: B [67%]

Question 12: What statement about the biological degradation of organic matter is not true?

A. The biological degradation of organic matter is a redox reaction.
B. Under anaerobic conditions biological degradation is less efficient.
C. Under anaerobic conditions no CO_2 is produced.
D. The amount of organic matter that is decomposed per time unit decreases when the supply of organic matter decreases.

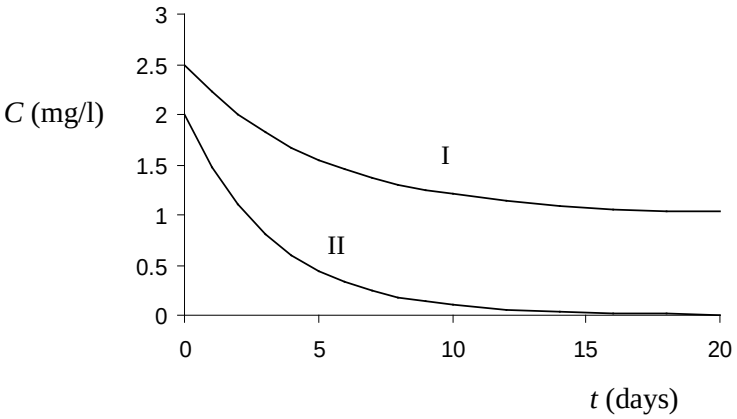
Correct answer: C [57%]

Question 13: At relatively low concentrations the adsorption process can be described by a linear isotherm. However, at higher concentrations the slope of the adsorption isotherm ($\Delta S/\Delta C$) often declines. What is the best explanation for this?

A. First the most preferred (energetically favourable) sites are occupied. When these sites are occupied the energetic benefit reduces and hence the additional adsorption also reduces.
B. At higher concentration the competition among molecules increases.
C. At low concentrations the adsorption sites are more accessible.
D. At higher concentrations the molecules become more repellent.

Correct answer: A [81%]

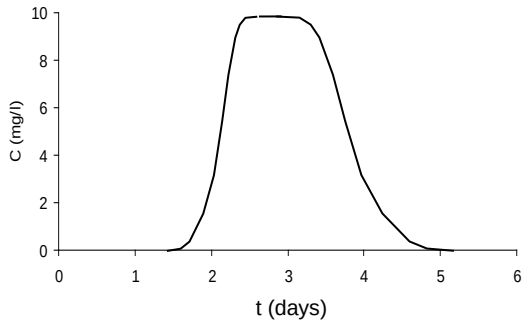
Question 14: Samples are taken from two different streams (I and II). The samples are analysed in a laboratory. In the figure below the concentration of dissolved organic carbon (DOC) is shown as a function of time at a temperature of 20 °C.



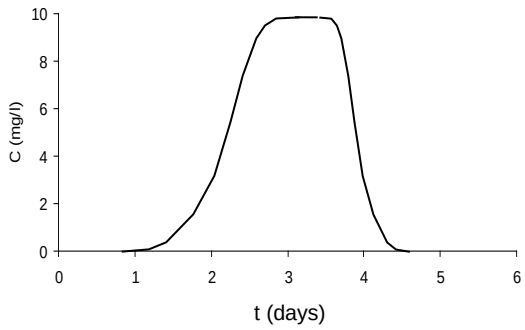
If we can assume that the DOC represents all the organic matter in the sample and that the decay of 1 mg organic carbon in both samples requires the same amount of oxygen, which statement of the biological oxygen demand after 5 days (BOD_5) and chemical oxygen demand (COD) is true?

A. BOD_5 stream I > BOD_5 stream II; COD stream I > COD stream II.
B. BOD_5 stream I > BOD_5 stream II; COD stream I < COD stream II.
C. BOD_5 stream I < BOD_5 stream II; COD stream I < COD stream II.
D. BOD_5 stream I < BOD_5 stream II; COD stream I > COD stream II.
BOD_5 stream I ~ 2.5 – 1.5 = 1 g/l; BOD_5 stream II ~ 2 – 0.5 = 1.5 g/l
COD is proportional to all organic carbon, i.e. the initial amount of DOC:
COD stream I ~ 2.5 g/l; COD stream II ~ 2
Correct answer: D [24%]

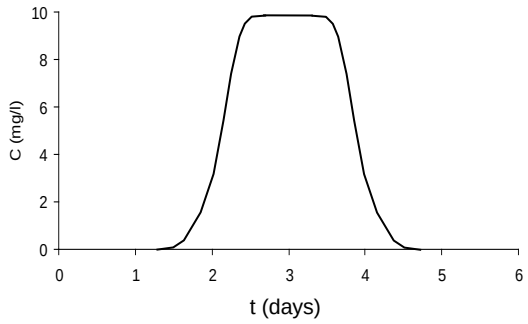
Question 15: By accident a pollutant is discharged for two days in an initially clean river. The pollutant mixes with the river and reaches a concentration of 10 mg/l. The river water has a velocity of 50 km/day. At 100 km from the discharge point the concentration is measured during several days, where *t* = 0 is the time at which the discharge of the pollutant began. How does the concentration profile look like when there is dispersion but no loss by degradation, volatilization or adsorption or dilution by tributaries?



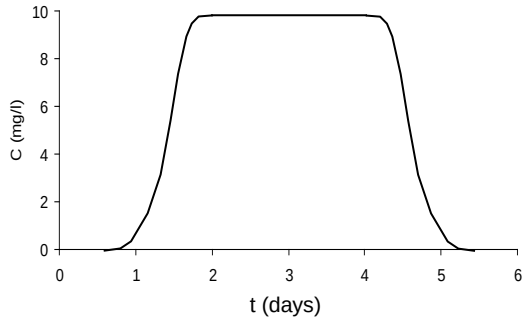
A.



B.



C.



D.

Correct answer: C [67%]

Section 3: Open questions *(25 points)*

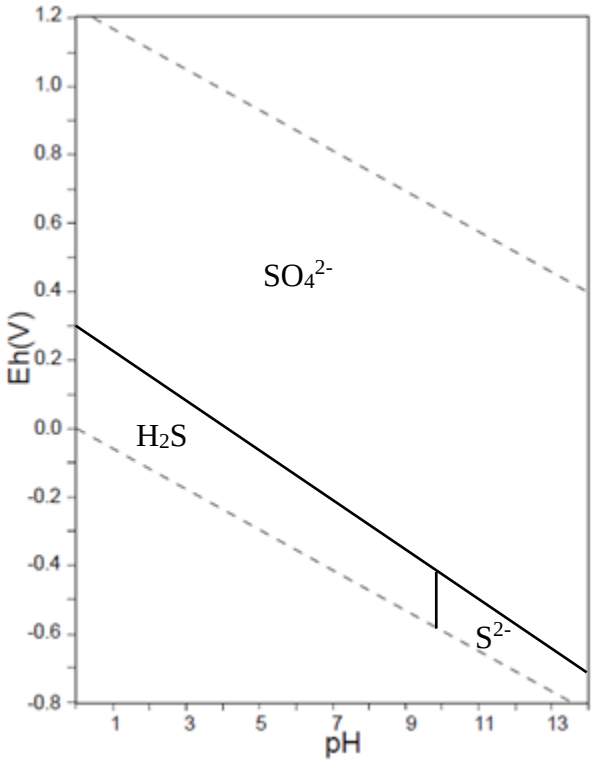
Question 16 (7 points)
The reduction of sulphate (SO_4^{2-}) can be described by:

$SO_4^{2-} + 10H^+ + 8e^- \rightleftarrows H_2S_{(aq)} + 4H_2O \quad Eh^0 = 0.30$ V

a. Draw the Eh-pH below on your answer sheet and draw in the graph the line at which the concentration SO_4^{2-} is equal to the concentration $H_2S_{(aq)}$. Indicate on which side of the line SO_4^{2-} is dominant and on which side $H_2S_{(aq)}$. (2)

$$Eh = Eh^0 - \frac{RT}{nF}\ln\frac{[H_2S]}{[SO_4^{2-}][H^+]^{10}} = 0.3 - \frac{8.314 \cdot 298}{8 \cdot 9.6 \cdot 10^4} \cdot 2.3log\frac{1}{[H^+]^{10}}$$
$$= 0.3 - \frac{8.314 \cdot 298}{8 \cdot 9.6 \cdot 10^4} \cdot 2.3log\frac{1}{[H^+]^{10}} = 0.3 + 0.0074 \cdot 10\log[H^+]$$

Eh = 0.3 – 0.074 pH [50%]



b. H_2S is a weak acid. The dissociation of H_2S can be written as:
$H_2S_{(aq)} \rightleftarrows 2H^+ + S^{2-} \qquad K = 1.14 \cdot 10^{-20}$
Draw in the same Eh-pH diagram the line at which the concentration $H_2S_{(aq)}$ is equal to the concentration S^{2-}. Indicate on which side of the line $H_2S_{(aq)}$ is dominant and on which side S^{2-}. (2)

$K = \frac{[s^{2-}][H^+]^2}{[H_2S]}$ when [S^{2-}] = [H_2S] $\rightarrow K = [H^+]^2 \rightarrow -\log K = -2\log[H^+]$

19.9 = 2 pH $\rightarrow$ pH = 10 [52%]

c. H_2S is a gas that is soluble in water ($H_2S_{(aq)}$) but can also escape to the atmosphere. This gas has a bed smell of rotten eggs. When you smell this gas, what does it say about the state of the water? (2)
When you smell H_2S, this means the water is strongly anaerobic. There is no oxygen in the water/sediment. Bacteria are decomposing organic matter under anaerobic conditions. Nitrogen, iron and manganese are also reduced. [69%]

d. Which law describes the equilibrium exchange between of a (dissolved) gas between water and atmosphere? Give name and formula. (1)
Henry's law: $C_a = H\, C_w$ [67%]

Question 17: Trophic state (6 points)
The trophic state is an indication of the biological response of an aquatic system to nutrient enrichment. One of the parameters commonly used to express the trophic state is the Secchi depth.

a. What is the Secchi depth? (2)
The Secchi depth is a measure for transparency or turbidity, and equal to the depth under water a white-black disk (◓) is still visible. [93%]

b. Explain when the Secchi depth is a good indicator of the trophic state and when not. (2)
The biological response in trophic systems is commonly an increase in algae. If transparency is mainly determined by the amount of algae, Secchi depth is a good indicator for the trophic state. If transparency is mainly determined by other factors such as suspended sediment or humic substances, the Secchi depth may not be a good indicator.
Also, when vegetation is present the turbidity will be lower for a given nutrient concentration and hence the Secchi depth will be larger than when no vegetation is present. [74%]

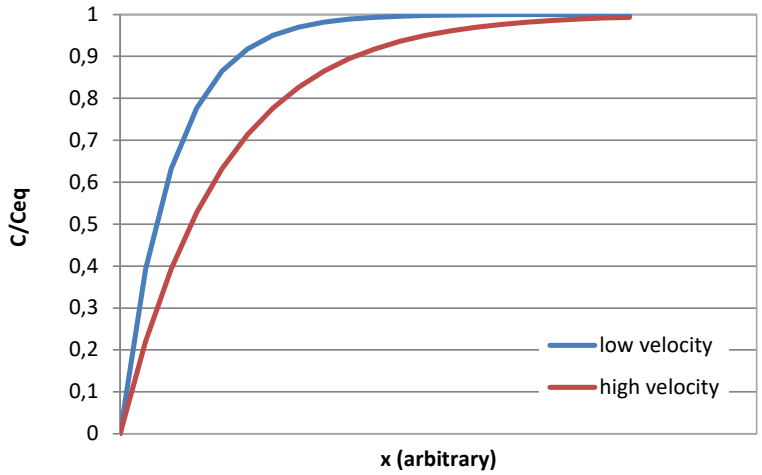
c. Can you give two other parameters that could indicate the trophic state of a water system? (2)
Nutrient concentrations (N, P), chlorophyll (algae) concentration, other measures for turbidity, presence of certain species. [55%]

Question 18 (8 points)
When the effluent leaves a waste water treatment plant and forms a stream like the Elsbeek in Enschede, the oxygen concentration is very low (assume zero). While flowing downstream oxygen from the air will diffuse into the water until an equilibrium is reached between the oxygen in the atmosphere and in the stream.

a. Write the differential equation that describes the oxygen concentration in the stream as a function of distance x to the effluent point. (Note that this process is the nonequilibrium exchange of oxygen between water and air and the distance can be derived from the flow velocity.) (2)
$\partial C/\partial t = k(C_{air}/H - C)$ and $t = x/v$ so $v\partial C/\partial x = k(C_{air}/H - C)$
Where C is oxygen concentration in water, t is the time, k is a first-order nonequilibrium coefficient representing the rate by which air diffuses into the water phase, C_{air} is the concentration of oxygen in air, H is the Henry-coefficient and C_{air}/H is the equilibrium concentration of oxygen in the stream, x is the distance in the stream and v is the velocity of the stream. [55%]

b. Solve the equation. (2)
$v\partial C/\partial x = k(C_{air}/H - C)$
$v\partial C/\partial x + kC = kC_{air}/H$
See appendix 1. $\alpha = v$, $\beta = k$, $\gamma = kC_{air}/H$
Solution: $C = ae^{-kx/v} + C_{air}/H$
At $x = 0 \rightarrow C = 0$, so
$0 = a + C_{air}/H \rightarrow a = -C_{air}/H$
$C = C_{air}/H - C_{air}/He^{-kx/v} = C_{air}/H(1-e^{-kx/v})$ [64%]

c. Draw a graph of the oxygen concentration as a function of x for a high en low velocity in the stream. (2)
Assume k is independent of velocity. [82%]



d. Can you think of at least two measures to increase the diffusion rate of oxygen into the stream? (2)
Mixing of water or enhancing the turbulence at the surface will increase the diffusion of oxygen to the water phase. Examples of measures are: waterfall, flow over/through rocks, fountain, bubbling air. [81%]

Question 19 (4 points)
The following toxicity data are given for arsenic:

MPA_{water}: 24 µg/l
$C_{b,\ water}$: 0.77 µg/l
$C_{b,\ sediment}$: 29 mg/kg
Log(K_p in l/kg): 3.82

a. Calculate the MPC for Arsenic in sediment. (2)
$MPA_{sed} = K_p\ MPA_{water} = 10^{3.82}$ (l/kg)·24 (µg/l) = 158566 µg/kg = 159 mg/kg
$MPC_{sed} = C_b + MPA_{sed}$ = 29 + 159 =188 mg/kg [55%]

b. As a water quality manager , what do you consider more useful to achieve: MPC_{water} or MPC_{sed}? Motivate your answer. (2)
MPC_{water}, because MPC_{sed} is derived from MPC_{water} and contains additional uncertainties (especially K_p). MPA_{sed} is defined as the equilibrium concentration in sediment corresponding to the MPA_{water}. So when MPA_{water} is achieved, in theory MPA_{sed} is also achieved irrespective to the value of K_p. In addition, the exposure for most organisms is via the water phase. [73%]