Exam Water Quality

Master Civil Engineering and Management

Course code:	201800023
Date:	October 28, 2019
Location:	Therm
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 a 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.
- You have 3 hours for the entire exam. Plan your exam well.
- 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.
- 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). Please do not write on the information sheet so it can be reused.

Good Luck!

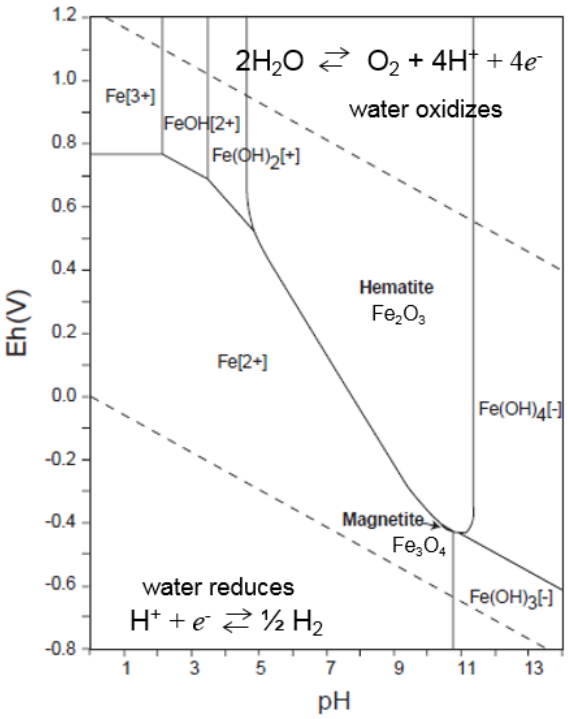
Section 1: True/False *(10 points)*

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

1. Nutrients are considered as priority pollutants according to the EU Water Framework Directive for which standards are defined for all water bodies. False [63%]
2. Atmospheric deposition is one of the sources for nitrogen pollution. True [100%]
3. Denitrification only takes place when organic matter is being decomposed. True [32%]
4. The octanol-water partition coefficient (K_{ow}) is a good indicator for the amount of dissolved organic matter (DOC) in water. False [58%]
5. White fish that feed on zoobenthos (small organisms that live on and in the sediment) sustain the eutrophic state of lakes. True [68%]
6. Sand is a product of physical weathering, clay a product of chemical weathering. True [89%]
7. Antibiotic resistance is understood as the ability of germs (e.g. bacteria) to defeat antibiotics, which are designed to kill these germs. As a consequence, antibiotics lose their function. True [100%]
8. The law of Lambert-Beer describes the depletion and reaeration of oxygen in a stream. False [79%]
9. When more of a chemical is adsorbed, the no-observed effect concentration in water increases. False [74%]
10. Nereda is a new treatment technology to remove heavy metals from waste water by precipitation. False [89%]

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

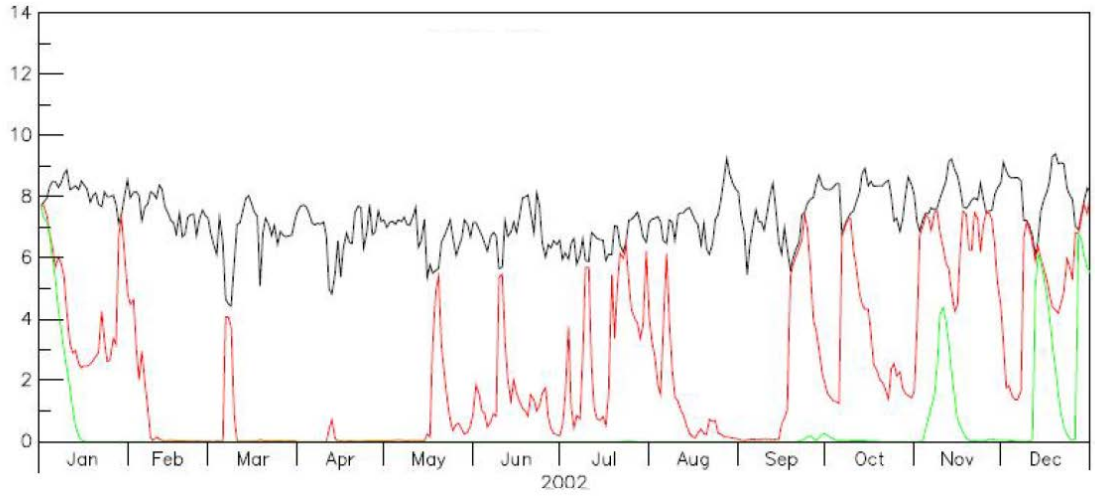
Question 11: Consider the following pH-Eh diagram: [74%]



Which statement related to this diagram is NOT true?

A. Free Fe^{3+} is primarily available at low pH.
B. Free Fe^{2+} is primarily available at anaerobic conditions.
C. When solid hematite (Fe_2O_3) is present there is no free Fe^{2+}.
D. The conversion between Fe^{3+} and $FeOH^{2+}$ is not a redox reaction.

Question 12: The graph below shows the simulated concentration of a water quality parameter in a reservoir at different depths (black is top layer, red is middle layer, green is lower layer) for the first year after filling when quite a bit of detritus is present. The reservoir is subject to thermal stratification. [89%]



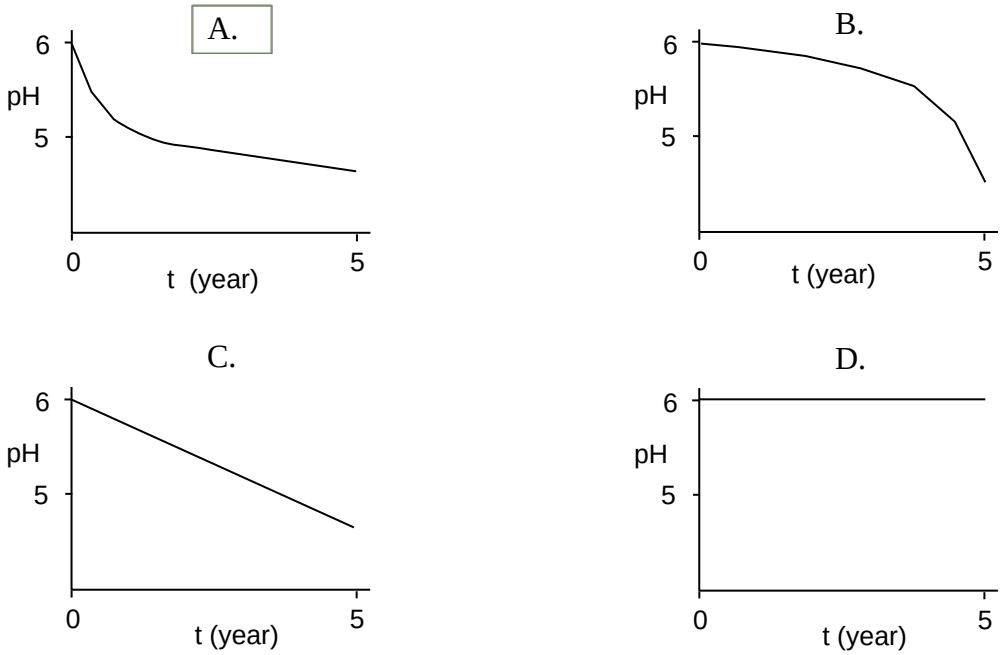
What water quality parameter is shown in the graph?

A. Total organic carbon (TOC in mg C/l)
B. Dissolved oxygen (DO in mg O_2/l)
C. Carbon dioxide (mg CO_2/l)
D. Methane (mg CH_4/l)

Question 13: What statement about algae is NOT true? [68%]

A. Algae are a sink for CO_2
B. Algae are on the base of the food chain.
C. Excessive amounts of algae in a lake can lead to anaerobic conditions.
D. Excessive amounts of algae in a lake can lead to enrichment with nutrients.

Question 14: A lake in Sweden has a volume of 10^6 m^3 and receives annually via atmospheric deposition 5000 mol H^+ which is not buffered (neutralized) and hence contributes to acidification of the lake. How will the pH in the lake in change in the next 5 years if the initial (t = 0) pH of the lake 6. [58%]



t = 0, $[H^+] = 10^{-6}$ pH = 5.222
t = 1, $[H^+] = 10^{-6} + 5000/10^9 = 1{\cdot}10^{-6} + 5{\cdot}10^{-6} = 6{\cdot}10^{-6} \rightarrow$ pH = 5.222
t = 2, $[H^+] = 6{\cdot}10^{-6} + 5{\cdot}10^{-6} = 1.1{\cdot}10^{-5} \rightarrow$ pH = 4.959
t = 3, $[H^+] = 1.1{\cdot}10^{-5} + 5{\cdot}10^{-6} = 1.6{\cdot}10^{-5} \rightarrow$ pH = 4.796
t = 4, $[H^+] = 1.6{\cdot}10^{-5} + 5{\cdot}10^{-6} = 2.1{\cdot}10^{-5} \rightarrow$ pH = 4.678
t = 5, $[H^+] = 2.1{\cdot}10^{-5} + 5{\cdot}10^{-6} = 2.6{\cdot}10^{-5} \rightarrow$ pH = 4.585

Question 15: What is NOT an advantage of a separated sewer system? [47%]

A. It reduces the direct discharge of contaminated surface runoff to surface water systems.
B. It makes the flow to a waste water treatment plant more constant which increases the treatment efficiency.
C. It avoids dilution of domestic and industrial waste water with less contaminated rain water.
D. The separated rainwater is allowed to infiltrate through porous pipes to recharge groundwater.

Section 3: Open questions *(25 points)*

Question 16 (4 points)
If the phosphate concentration in effluent water of a water treatment plant is still high, ferric chloride ($FeCl_3$) can be added to reduce the phosphate concentration by precipitation of iron(III)phosphate:

$Fe^{3+} + PO_4^{3-} \rightleftarrows FePO_4$

The following information is given: $\Delta G_f^0(Fe^{3+})$ = - 4.6 kJ/mol; $\Delta G_f^0(PO_4^{3+})$ = - 1018.8 kJ/mol and $\Delta G_f^0(FePO_4)$ = - 1183.3 kJ/mol.

a. Calculate the equilibrium constant for the reaction given above under standard conditions (1 atm and 25 °C (298 K)) (2) [74%]

$\Delta G_r^0 = \Delta G_f^0(FePO_4) - \Delta G_f^0(Fe^{3+}) - \Delta G_f^0(PO_4^{3-}) = -1183.3 + 4.6 + 1018.8 = -159.9$ kJ/mol.

$K = \exp\left(-\frac{\Delta G_r^0}{RT}\right) = \exp\left(-\frac{-159.9 \cdot 10^3}{8.314 \cdot 298}\right) = \exp(+64.5) = 1.1 \cdot 10^{28}$

From this answer can be deduced that $FePO_4$ is essentially insoluble and that all phosphate will precipitate when sufficient ferric chloride is added.

b. If the concentration of phosphate in the effluent water is 5 mg PO_4^{3-}/l, how much ferric chloride (in mg $FeCl_3$/l) should at least be added to remove all phosphate if we assume that all iron will be used for the precipitation of iron(III)phosphate. (2) [50%]

$M(PO_4^{3-})$ = 31+4*16 = 95 g/mol. 5 mg PO_4^{3-}/l = 5/95 = 0.0526 mmol/l, hence 0.0526 mmol Fe^{3+} (= $FeCl_3$) should be added. $M(FeCl_3)$ = 55.85+3*35.45 = 162.2 g/mol, so 0.0526*162.2 = 8.5 mg/l $FeCl_3$ should be added.

Question 17 (15 points)
Some UT students have been working on a project dealing with the water quality in the Citarum River on Java, Indonesia. This is one of the most polluted rivers in the world. They wanted to investigate the contribution of the different sources of pollution to the contamination level of the river. For this a simple model is developed based on the schematic in Figure 1.

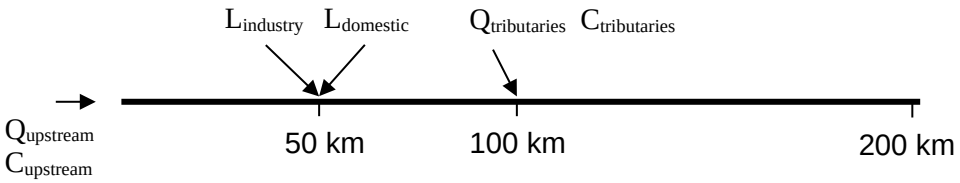


Figure 1. Schematic of the Citarum River. Q is discharge (m^3/s), C is concentration (kg/m^3) and L is load (kg/s). The km indicates the distance along the river starting 50 km upstream of the city of Bandung. Near the city of Bandung domestic and industrial waste water is discharged into the river. At 100 km some tributaries join the river. The concentrations in the upstream part of the river and in the tributaries are determined by agricultural loads. At 200 km the river enters a reservoir.

The first interest is BOD which represents the amount of degradable organic matter in the river.

a. What is BOD and why is it bad for the water quality? (2) [58%]
BOD is Biological Oxygen Demand. Organic matter requires oxygen for degradation. The consumed oxygen is not available for other biota in the water phase. The oxygen concentration can drop below levels that are harmful for fish and other species.

The following data is given (note that data are fictive):
$Q_{upstream}$ = 1000 m^3/s
$C_{upstream}$ = 5 mg/L
$L_{industry}$ = 6 kg/s
$L_{domestic}$ = 8 kg/s
$Q_{tributaries}$ = 500 m^3/s
$C_{tributaries}$ = 5 mg/L
u = 0.58 m/s (average flow velocity in river)

C and L represent BOD. Assume that the change in discharge of the river due to the industrial and domestic loadings near Bandung is negligible. All values are constant in time.

b. Draw the BOD (C) over the length of the river. For this, calculate BOD at 50, 100 and 200 km and use these values in your graph. Dispersion and other processes (e.g. adsorption, degradation) can be ignored. (3) [74%]

At x = 0 km, C is 5 mg/l.
At 50 km a load of 6+8 = 14 kg/s enters the river:
$Q_3C_3 = Q_1C_1 + Q_2C_2 = Q_1C_1 + L$
$C_3 = (Q_1C_1 + L)/ Q_3$ = (1000 m^3/s ·0.005 kg/m^3 + 14 kg/s)/ 1000 m^3/s = 0.019 kg/m^3 = 19 mg/l
At 100 km a tributary enters the river:
$Q_3 = Q_1 + Q_2$ = 1000 m^3/s + 500 m^3/s = 1500 m^3/s
$Q_3C_3 = Q_1C_1 + Q_2C_2$
$C_3 = (Q_1C_1 + Q_2C_2)/ Q_3$ = (1000 m^3/s ·0.019 kg/m^3 + 500 m^3/s ·0.005 kg/m^3)/ 1500 m^3/s = 0.0143 kg/m^3 = 14.3 mg/l
See figure below (discharge is not asked for).

c. What is the largest source of the BOD that flows into the reservoir? Explain your answer. (2) [66%]

Load agriculture: $L_{agriculture} = Q_{upstream}C_{upstream} + Q_{tributaries}C_{tributaries}$ =
1000 m^3/s ·0.005 kg/m^3 + 500 m^3/s ·0.005 kg/m^3 = 7.5 kg/s
$L_{agriculture}$ = 7.5 kg/s
$L_{industry}$ = 6 kg/s
$L_{domestic}$ = 8 kg/s
So domestic is the largest source.

Generally BOD reduces over time. Assume that this can be described by a first-order rate:

$$\frac{\partial C}{\partial t} = -kC \quad \text{or} \quad \frac{\partial C}{\partial x} = -\frac{k}{u}C$$

where k is the decay coefficient.

d. Solve the equation for C as a function of x. (3) [86%]

Solution:

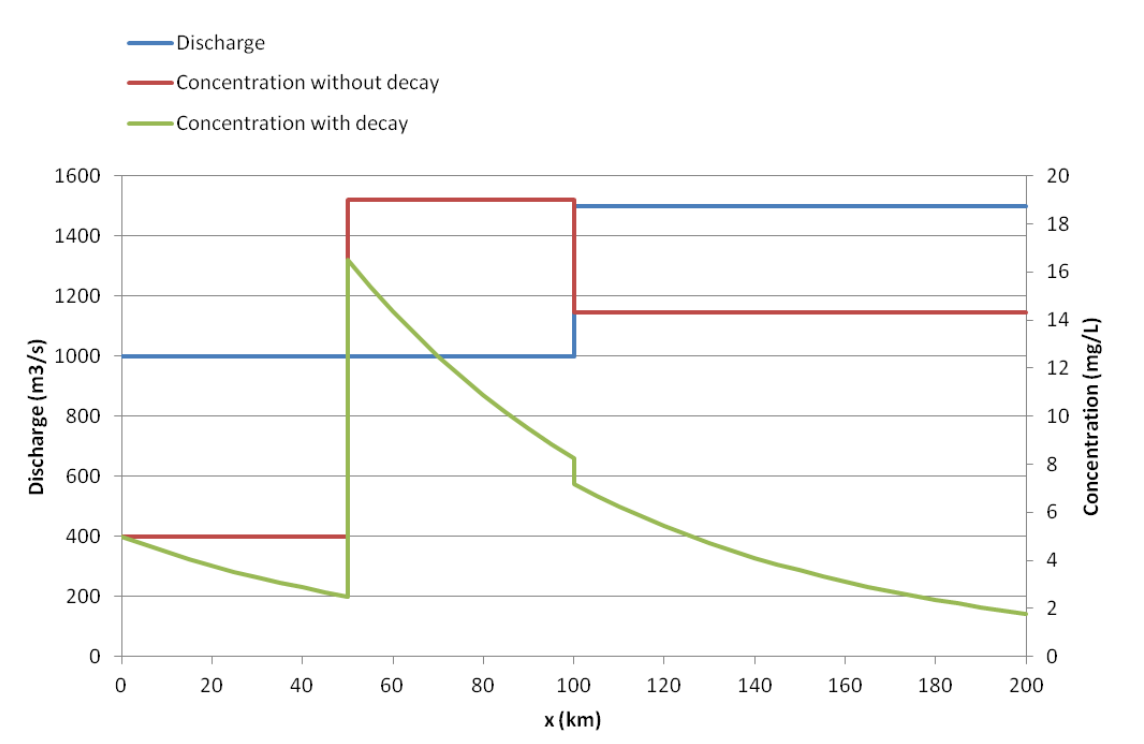
$$C = C_0 e^{-\frac{kx}{u}}$$

Assume that the half-life of BOD in the Citarum river is 1 day (k = 0.69 day^{-1}).

e. Draw in the same graph as for question 17b the BOD (C) over the length of the river but now including degradation. Use a different colour or dashed line and again use calculated values. Assume that the concentration upstream and in the tributaries remain the same. (3) [54%]

At x = 0 km, C is 5 mg/l.
$k = \ln(2)/ t_{1/2} = \ln(2)/1 = 0.69$ d^{-1}
u = 0.58 m/s = 0.58·60·60·24 = 50 km/d

At 50 km the concentration is reduced to:
$C = C_0 \exp(-kx/u)$ = 5·exp(- 0.69·50/50) = 2.5 mg/l (half the original concentration)
Then the concentration increases due to the industrial and domestic load (6+8 = 14 kg/s):
$Q_3C_3 = Q_1C_1 + Q_2C_2 = Q_1C_1 + L$ = (1000 m^3/s ·0.0025 kg/m^3 + 14 kg/s)/ 1000 m^3/s = 0.0165 kg/m^3 = 16.5 mg/l
This is now the new C_0. 50 km farther (at 100 km) the concentration is reduced to:
$C = C_0 \exp(-kx/u)$ = 16.5·exp(- 0.69·50/50) = 8.25 mg/l (half the original concentration)
At 100 km a tributary enters the river and the concentration becomes:
$Q_3 = Q_1 + Q_2$ = 1000 m^3/s + 500 m^3/s = 1500 m^3/s
$Q_3C_3 = Q_1C_1 + Q_2C_2$
$C_3 = (Q_1C_1 + Q_2C_2)/ Q_3$ = (1000 m^3/s ·0.0085 kg/m^3 + 500 m^3/s ·0.005 kg/m^3)/ 1500 m^3/s = 0.0073 kg/m^3 = 7.3 mg/l
This is now the new C_0. 100 km farther (at 200 km) the concentration is reduced to:
$C = C_0 \exp(-kx/u)$ = 7.3·exp(- 0.69·100/50) = 1.8 mg/l (a quarter of the original concentration)



f. What measures could be taken to reduce BOD in the river? (2) [63%]
Reduction source: Waste water collection, waste water treatment, awareness of discharging waste
Increase reaeration: creating water falls, fountains, placing rocks, etc.

Question 18 (3 points) [65%]
Give three pathways pharmaceuticals can enter surface water and/or ground water.
(see slides Lara)
Intake → excretion (most of it) → sewer → WWTP (poor treatment) → effluent
Intake → excretion (most of it) → sewer → overflow
Disposal in sink → sewer → etc.
Intake by animals → manure → application to land → groundwater/surface water
Disposal with garbage → landfill → seepage to groundwater

Question 19 (3 points) [63%]
Define the Maximum Permissible Concentration (MPC) and Negligible Concentration (NC) and explain the difference.
The MPC is the concentration at which **95%** of the species in an ecosystem is protected or at which 5% is affected by this contaminant. The effects are **chronic** effects rather than acute, so the exposure should be sufficiently long. The MPC is used for **short term**. **$MPC = C_b + MPA$**
The NC is the concentration in which **uncertainties** are taken into account and all species are supposedly protected. It is used as target or **long term** standard **$NC = C_b + MPA/100$.**