Fill in your name and ID No. in the space above. There should be 12 pages including this one.

The exam is closed book, and two double-sided sheets of notes are permitted. **No collaboration with others!**

For multiple choice questions, choose the **single, BEST** answer.

For work-out problems, write down all general equations used and intermediate algebraic steps. Show all your work. Failure to do so will result in a lower score.

You have 50 minutes to complete the exam.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Points earned</th>
<th>Total points possible</th>
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<tbody>
<tr>
<td>Multiple choice:</td>
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<td>Workout problem 1:</td>
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<td>Workout problem 2:</td>
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<td>Workout problem 3:</td>
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<td><strong>Total:</strong></td>
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**Answers to the multiple choice questions.** Circle the letter that corresponds to your answer for each of the multiple choice questions. Please note that only the answers you provide on this sheet will be graded.

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1. A  B  C  D  E
2. A  B  C  D  E
3. A  B  C  D  E
4. A  B  C  D  E
5. A  B  C  D  E
6. A  B  C  D  E
7. A  B  C  D  E
8. A  B  C  D  E
9. A  B  C  D  E
10. A  B  C  D  E
I. (30 pts total) 10 Multiple choice problems worth 3 points each. Circle the answer that is the most appropriate or closest numerically to your answer and then select that answer on the answer sheet (page 2).

1. Turbulent flows are in general NOT
   a. Random
   b. Non-linear
   c. Irrotational
   d. Diffusive
   e. Dissipative

2. The correlation coefficient in turbulent flows is used to measure
   a. The size of large-scale eddy structures
   b. The relationship between eddy size and viscosity
   c. The energy content of Kolmogorov-scale eddies
   d. The mean flow velocity
   e. None of the above

3. The integral scales in a turbulent flow (e.g. integral time scale, integral length scale) relate to the
   a. Size and rotation speed of the large-scale eddies in a flow
   b. Size and rotation speed of the Kolmogorov scale eddies in a flow
   c. Integral of the correlation coefficient
   d. Both (a.) and (c.)
   e. Both (a.) and (c.)

For problems 4 through 8 refer to the following data for Cowaselon Creek, NY:

Velocity: \( U = 0.17 \) m/s
Width: \( B = 10.7 \) m
Depth: \( H = 0.3 \) m
Slope: \( S = 0.00043 \)

Assume the creek channel is straight and uniform.
4. Using the shallow flow assumption (the hydraulic radius is approximated by $R_{hy} = H$), what value is the Manning friction coefficient for this flow closest to?
   a. 0.035 
   b. 0.040 
   c. 0.045 
   d. 0.050 
   e. 0.055 

5. The shear velocity in m/s for the flow is best approximated by
   a. 0.005 
   b. 0.010 
   c. 0.025 
   d. 0.035 
   e. None of the above 

6. The vertical turbulent diffusion coefficient in cm$^2$/s is closest to
   a. 7.2 
   b. 5.3 
   c. 0.16 
   d. 0.072 
   e. 0.053
7. The longitudinal dispersion coefficient according to the formula by Deng et al. (2002) is given by

\[ D_L = \frac{0.15}{8\epsilon_0} \left( \frac{B}{H} \right)^{5/3} \left( \frac{U}{u_*} \right)^2 u_* H \]

where

\[ \epsilon_0 = 0.145 + \frac{1}{3520} \left( \frac{U}{u_*} \right) \left( \frac{B}{H} \right)^{1.38} \]

\[ = 0.3311 \]

Based on this formula, the dispersion coefficient in m²/s in Cowaselon Creek is closest to

a. 2.1
b. 3.4
c. 4.5
d. 5.3
e. 7.9

8. If an instantaneous point source of bacteria with die-off coefficient \( k = 0.5 \text{ d}^{-1} \) is injected at \( x = 0, t = 0 \), at what distance downstream in meters is the bacteria cloud 800 m long in the longitudinal (downstream) direction. Approximate the cloud width by \( \pm \sigma \).

a. 250
b. 500
c. 1000
d. 2500
e. 5000
9. Which of the following is an example of a homogeneous reaction?
   a. Aeration at the air-water interface
   b. Boundary exchange at the sediment-water interface
   c. Radioactive decay of dissolved Radon gas
   d. Dissolution of paint on the bottom of a boat
   e. None of the above.

10. Reaction kinetics tells you
    a. If a chemical reaction is possible
    b. What the equilibrium concentration of a substance in a chemical reaction will be
    c. The rate at which a chemical reaction takes place
    d. What the equilibrium partition coefficient is proportional to
    e. None of the above
II. (70 pts total) 3 Work-out problems. Problem parts are valued as noted. Show all your work and indicate which equations you are using to solve each part.

1. (20 pts) Some engineers performed a dye study in a river to determine the mixing characteristics. They injected 20 kg of Rhodamine WT instantaneously at $x = 0$ and measured the concentration at a downstream point $x = 10$ km. The following figure presents their data:

   ![Rhodamine WT concentration](image)

   The physical characteristics of the river channel were:

   - Depth: $H = 5$ m
   - Width: $B = 100$ m
   - Velocity: $U = 0.3$ m/s

   Based on this experiment, answer the following questions:

   a. What is the volume flow rate in the river? (7 pts)
   b. What is the experimentally derived dispersion coefficient? (10 pts)
   c. A company wants to dump Arsenic in the river. If the maximum allowable concentration of Arsenic in the river is 0.05 mg/l, what is the maximum mass flow rate of arsenic in kg/day that the company can discharge for the flow conditions given above? (3 pts)
Use this page to continue your solution to the work-out problems.
2. (30 pts) A wastewater treatment plant (WWTP) discharges phosphate (PO$_4^{3-}$) at a constant rate of $\dot{m} = 30$ mg/s into a shallow river (see sketch below).

![Sketch of wastewater input](image)

The physical attributes of the river are:
- Depth: $H = 0.27$ m
- Width: $B = 10$ m
- Velocity: $U = 0.37$ m/s
- Slope: $S = 0.001$

Given these data, answer the following questions:

a. What are the turbulent diffusion coefficients in the vertical ($D_{t,z}$) and lateral ($D_{t,y}$) directions? (5 pts)
b. What is the downstream distance $L_y$ where the injection first touches the stream banks? Assume a total cloud width at this location of $\pm \sigma$. (5 pts)
c. The injection is well-mixed in the lateral at the location $L = 450$ m. What is the phosphate concentration at this location assuming there is no chemical or biological reaction? (5 pts)
d. If phosphate degrades by a first-order decay process with $k = 1 \cdot 10^{-4}$ s$^{-1}$, what would be the concentration at $L = 450$ m? (5 pts)
e. At what point downstream is the phosphate concentration reduced to one half of its initial concentration? (5 pts)
f. Why are the answers to parts (d.) and (e.) independent of the longitudinal dispersion coefficient? (5 pts)
3. (20 pts) An autosampler at the intake to a fish farm recorded the passage of an instantaneous release of Chlorine. The maximum recorded concentration was 0.2 mg/l and the total mass measured to pass the station was 45 kg. The river has a nearly uniform cross-section, and the physical properties near the fish farm intake were

- Depth: \( H = 0.8 \, \text{m} \)
- Width: \( B = 45 \, \text{m} \)
- Volume flow rate: \( Q = 20 \, \text{m}^3/\text{s} \)
- Slope: \( S = 0.0005 \)

a. Use the approximate formula from Fischer et al. (1979) to determine the longitudinal dispersion coefficient:

\[
D_L = 0.011 \frac{B^2 U^2}{u_h}
\]

where \( u_h \) is the shear velocity. (5 pts)

b. Use the Peclet number to determine if this river is advection or diffusion (dispersion) dominant. (3 pts)

c. Assuming there are no reactions (the contaminant is a conservative substance), estimate where the release took place. (7 pts)

d. If the contaminant followed a 1st-order decay process, would it be possible to determine the release location from the given data? What other information would you need? Explain your answer. (5 pts)
Use this page to continue your solution to the work-out problems.