Student number:

THIS QUESTION PAPER MUST BE HANDED-IN TO THE INVIGILATOR AT THE END OF THE EXAMINATION

CRANFIELD UNIVERSITY

Examination

SCHOOL OF WATER, ENERGY AND ENVIRONMENT
MSc ENVIRONMENTAL WATER MANAGEMENT
MSc COMMUNITY WATER AND SANITATION

SURFACE AND GROUNDWATER HYDROLOGY

Thursday 5 January 2017: 16:00 - 18:00 (2hrs)

Closed Book

INSTRUCTIONS TO CANDIDATES:

- Please write your answers (and workings, where appropriate) on the question sheet only and enter your student number on the top of the first sheet.
- Answer **ALL** the questions.
- Do not spend too long on any question you find difficult. Leave it and come back to it later.
- Numerical answers must include the units.
- Use the formula sheet provided where appropriate.

EXAM MATERIALS:

This paper is provided with **NO** additional materials.

1. Which four weather parameters need to be measured to estimate the reference evapotranspiration using the Penman-Monteith formula? [2 marks]

a)	b)
c)	d)

2. A dam measuring 50 m wide holds back a reservoir 3 m deep and 200 m long.

(a) Calculate the force exerted by the water on the dam. [5 marks]

(b) Define the direction of the force. [2 marks]

(c) Define the position at which the resultant force acts. [2 marks]

3. Two soil samples, A and B, are found to have the following properties:

Sample	Total pore space (% volume)	Water content at field capacity (% volume)	Water content at wilting point (% volume)
A	35	16	6
B	43	37	18

a) If Sample B were to form an unconfined aquifer, what would be its specific yield? [3 marks]

b) Which sample has the greatest Available Water? Show your workings. [3 marks]

4. A particular weather station has reliable rainfall data for 55 years. In 42 of those years the annual rainfall total was greater than 500 mm.

   a) For that station, estimate the return period of a year with an annual rainfall $\leq$ 500 mm? [2 marks]

   b) Explain precisely what this means. [2 marks]

5. Thirty-five consecutive years of historical river discharge data were collated for a particular gauging station and a relationship was derived between the maximum discharge in each year and its annual exceedance probability.

   a) A statistical analysis showed that there was a significant correlation between the maximum discharge in the year and the year in which it was recorded. In other words, there is a trend between peak discharge and year. What does this tell us about the data and what are the implications for the relationship between the discharge and its annual exceedance probability? [3 marks]

   b) Briefly describe three possible reasons for this observed correlation. [3 marks]

6. The geological log for a borehole is given in the table below. The rest water level in the borehole is 3 m below ground level. The hydraulic conductivity of the sandstone is estimated at 10 m day^{-1} and the hydraulic conductivity of the clay is estimated at 3×10^{-5} m day^{-1}

Depth interval (m below ground level)	Lithological description
0 to 7	Clay
7 to 36	Sandstone
36 to 45	Clay

a) Is the aquifer confined or unconfined? Briefly explain your answer. [3 marks]

b) If the ground elevation at the borehole is 100 m above sea level, what is the total head of water in the borehole? [4 marks]

c) Calculate the transmissivity of the sandstone aquifer. [4 marks]

7. Water flows steadily at 0.25 m s^{-1} though a horizontal pipe with a circular cross-section (12 cm diameter) that constricts to 6 cm diameter.

(a) What is the water velocity in the constricted section of the pipe, and what principle is used to calculate this? [6 marks]

(b) Draw a diagram of the pipe with a piezometer in both the original and constricted sections, indicating the relative water level expected in each piezometer. Explain what a piezometer measures and where the reading is measured from. [5 marks]

8. A sloping field in Bedfordshire has a sandy soil with a large proportion of fine (small) sand particles. The field is used for vegetable production in the summer. Textbooks suggest that such a soil should have a final (terminal) infiltration rate of about 30 mm hr^{-1}. However, overland flow was observed during a winter rainfall event that had a maximum intensity of only 15 mm hr^{-1}. Suggest three reasons why this may have occurred.

[6 marks]

9. Explain why analyses of datasets from a pumping test using Logan's equation and Jacob's equation might give very different values of transmissivity [4 marks]

10.

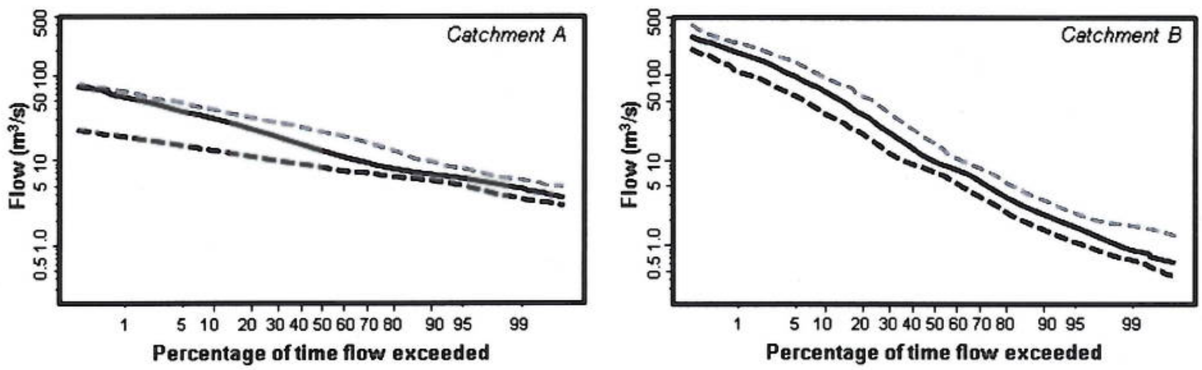
11. Which of the following methods of flow measurement would be most suitable for each of the following situations given in the table below? Circle the most suitable method in each case. [4 marks]

A. Dilution gauging
B. Velocity - area method using a current meter
C. Acoustic Doppler Current Profiler
D. Velocity - area method using floats
E. Weir or Flume
F. Volumetric gauging (e.g. bucket and stopwatch)

A hand-pump, where we want to know the discharge under normal pumping conditions.	A	B	C	D	E	F
A turbulent mountain stream where a single measurement of discharge is required.	A	B	C	D	E	F
A medium sized river, 7m wide and 1m deep, where continuous monitoring is required for flood warning.	A	B	C	D	E	F
A small river, 3m wide and 0.3m deep, where an approximate estimate of discharge is required.	A	B	C	D	E	F

11. The figure below shows annual and seasonal flow duration curves derived from continuous discharge measurements at gauging stations in two different catchments.

(a) Identify and briefly explain three characteristics of the catchments or their climate which could cause the differences in the flow duration curves for the two catchments [6 marks]



Key: Black line - annual; grey dashed line - December to March; black dashed line - June to September.

12. Describe how the shape of the downstream flood hydrograph can be modified by extensive urban expansion in a catchment? Provide <u>two</u> examples. [3 mark]

13. A floating orange was used to estimate the velocity of flow in a river. The channel is approximately rectangular, with a width of 6 m and a depth of 0.35 m. The times taken for the orange to travel 10 m are shown in the table below. Estimate the discharge of the river. State any assumptions that you have made. [6 marks]

Test	Location	Time (seconds) to travel 10 m
1	Close to right bank	40
2	Centre	15
3	Close to left bank	30

14. The following field notes were taken at two monitoring boreholes which are installed 700 m apart.

	Borehole	
	A	B
Elevation of top of borehole casing (m above sea level)	65	62
Depth to water (from top of casing) (m)	15	21

Calculate the following:

a. The total heads at A and B. [4 marks]

b. The hydraulic gradient between A and B. [2 marks]

c. Which direction is groundwater flowing and explain why; A to B or B to A? [2 marks]

15. Groundwater is abstracted from a borehole at a rate of 30 $m^3\ hr^{-1}$ from an aquifer with a transmissivity of 350 $m^2\ d^{-1}$ and a storage coefficient of 0.01. Using Jacob's equation (below), predict the drawdown in a well at a distance of 100 m from the borehole after 80 days of pumping. [4 marks]

$$s = \left[\frac{2.303Q}{4\pi T}\right] \bullet \log_{10}\left(\frac{2.25Tt}{r^2 S}\right)$$

16. The average annual rainfall over a catchment of 150 km^2 is 750 mm yr^{-1} and the estimated actual evapotranspiration, AET, is 500 mm yr^{-1}. Assuming that there are no other significant inputs or outputs, what is the average discharge of the river? Express your answer in $m^3\ s^{-1}$. [6 marks]

17. The Greensand aquifer at Silsoe receives approximately 160 mm of annual recharge, mainly in the winter months, after the soil has reached field capacity in October or early November.

(a) If the aquifer has a storativity of 0.1, estimate the expected winter rise in water table (in m) corresponding to this recharge. [2 marks]

(b) After the winter "recharge season", groundwater levels drop. Why? [2 marks]

You may use this page for rough notes / calculations

Surface & Groundwater Hydrology

Some basic formulae

FORCE
An unopposed force makes a body accelerate.
Force (N) = mass (kg) x acceleration (m/s^2) .... **F = ma**
1 Newton (N) = 1 kgm/s^2

WORK / ENERGY
Work is done when the force moves through a distance.
The energy transferred, or "work done", is
Work done (Nm or J) = force (N) x distance (m) .... **W=Fd**
1 Joule (J) = 1 Nm

POWER
The power is the rate of doing work
Power (J/s or W) = work done (J) / time (s) .... **P=W/s**
1 Watt (W) = 1 J/s

WEIGHT
The weight is the force due to gravity
Weight (N) = m (kg) x g (m/s^2) .... **w=mg**
g = 9.81 m/s^2 at the earth's surface

DENSITY
The (mass) density **ρ** ("rho") is the mass per unit volume
Density (kg/m^3) = mass (kg) / volume (m^3) .... **ρ=m/V**
The density of pure water is around 1000 kg/m^3
The "specific gravity" (SG) of a material is its density relative to water. (SG_{water} =1)

PRESSURE
The pressure is the force per unit area
Pressure (N/m^2 or Pa) = force (N) / area (m^2) .... **p=F/A**
1 Pascal (Pa) = 1 N/m^2)
The relationship between pressure and depth is .... **p=ρgh**

This allows us to express pressures as the equivalent "head of water" (m)

Atmospheric pressure is approximately 10m head of water at sea level, which is 98 kN/m^2
(Note 1 bar ≡ 100 kN/m^2 by definition)

Pressures may be given as absolute values or gauge values (ignoring atmospheric pressure)

FORCES ON SURFACES

Resultant force on any surface (e.g. horizontal or vertical rectangular sluice gates and circular gates),.. $F = \rho g a\bar{y}$

where *a* is the area of the surface
and $\bar{y}$ is the depth from the water surface to the centre of area of the surface.

For a horizontal surface, this simplifies to .... $F = \rho g A h$

CONTINUITY

Discharge, Q (m^3/s) = velocity of flow (m/s) x area of flow (m^2) .... **Q=vA**
Continuity in steady flow requires that inflow equals outflow............ **$Q_1=Q_2$; $v_1A_1 = v_2A_2$**

ENERGY

Three components of energy are considered interchangeable.
In units of energy per unit weight (Nm/N):
Pressure energy =... **p/ρg**
Kinetic energy = ... **$v^2/2g$**
Potential energy = ... **z**

The "total energy" of a fluid is the sum of these three components.
If friction losses are ignored, energy must be conserved (Bernouilli's equation)

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + Z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + Z_2$$

MOMENTUM

Momentum (kgm/s) is mass (kg) x velocity (m/s)... **M=mv**

Force = rate of change of momentum .... $F = \rho Q(v_1 - v_2)$

CHEZY EQUATION

$$v = C\sqrt{RS}$$

Where v is the mean velocity (the area divided by the discharge)
C is the Chezy coefficient
R is the hydraulic radius (the area divided by the wetted perimeter)
S is the longitudinal slope

MANNING EQUATION

$$v = \frac{1}{n} R^{2/3} S^{1/2}$$

Where v is the mean velocity (the area divided by the discharge)
n is the Manning's roughness coefficient
R is the hydraulic radius (the area divided by the wetted perimeter)
S is the longitudinal slope