Opportunity 1

UNAM

UNIVERSITY OF NAMIBIA

FACULTY	AGRICULTURE, ENGINEERING AND NATURAL SCIENCES		
SCHOOL	ENGINEERING AND THE BUILT ENVIRONMENT		
DEPARTMENT	CIVIL AND MINING ENGINEERING		
SUBJECT	HYDROLOGY FOR ENGINEERS		
SUBJECT CODE	I3741VH		
DATE	JUNE, 2024		
DURATION	2 HOURS	**MARKS**	80

1st OPPORTUNITY EXAMINATION

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This question paper consists of **9** pages Including this front page and graph sheets.

Instructions

1. **Closed** book examination.
2. Read the questions carefully.
3. The paper contains **5** questions.
4. **Attempt any four (4) questions** for full marks.
5. Some relevant equations, tables and charts have been provided.
6. Answers should be brief and to-the-point and where necessary be supplemented with neat sketches.
7. Marks for each question are indicated.
8. Any missing or 'wrong' data may be assumed suitably giving proper justification.
9. State all assumptions clearly.

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Q1 (20 marks)

(a) Briefly describe the five (5) key components of the hydrologic cycle *(5 marks)*

(b) In a given year, a catchment with an area of 2500km^2 received 130 cm of precipitation. The average flow rate measured in the river draining the catchment was 30m^3 /s.

i) How much runoff reached the river for the year (in m^3)?

ii) Estimate the amount of water lost due to the combined effects of evapotranspiration and infiltration to groundwater (in m^3)?

iii) How much precipitation is converted into river runoff (in percentage)? *(5 marks)*

(c) With the measurements in the following table, calculate the soil moisture flux q (cm/day) between depth 0.5m and 0.8m in each week. Hydraulic conductivity $K = 240(-\Psi)^{-2.3}$ (K in cm/day and Ψ in cm). Use the average suction head to derive hydraulic conductivity. For 1km^2 area, how much water has passed the layer between 0.5m and 0.8m in these two weeks (in m^3)?

Week	Total head at 0.5m (cm)	Total head at 0.8m (cm)
1	-70	-105
2	-80	-120

(10 marks)

Q2 (20 marks)

(a) What is a Unit Hydrograph? *(5 marks)*

(b) Estimate the evaporation rate (in mm/day) from an open water surface based on the energy balance method. The net radiation is 1000 W/m^2 and air temperature is 20°C, assuming that the sensible heat or ground heat flux is negligible. Take the water density as 1000kg/m^3. *(5 marks)*

(c) A lake had a water surface elevation of 103.200 m above datum at the beginning of a certain month. In that month, the lake received an average inflow of 6.0 m^3 /s from surface runoff sources. In the same period, the outflow from the lake had an average value of 6.5 m^3 /s. Further, in that month, the lake received a rainfall of 145 mm and the evaporation from the lake surface was estimated as 6.10 cm. Write the ***water-budget equation*** for the lake and calculate the water surface elevation of the lake at the end of the month. The average lake-surface area can be taken as 5000 ha. Assume that there is no contribution to or from the groundwater storage *(10 marks)*

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Q3 (20 marks)

(a) Enumerate the basic components of a hydrograph *(5 marks)*

(b) Estimate the downstream hydrograph using the ***Muskingum method*** of River flood routing with $K = 3hr$ and $X = 0.3$. The time interval is 3 hours. The upstream hydrograph is as follows:

Time (hr)	0	3	6	9	12	15	18
Inflow (m^3/s)	1	3	9	15	13	10	6

(15 marks)

Q4 (20 marks)

A river catchment has a 2 hour unit hydrograph with the ordinates 0, 3, 11, 35, 55, 66, 63, 40, 22, 9 and 2 m^3/s. Assume that the base flow at time $t = 0$ hour is 20 m^3/s and linearly increases to 44 m^3/s at $t = 24$ hours.

i) Compute the hydrograph resulting from two successive 2 hour periods of effective rain of 2.0cm and 1.5 cm respectively.

ii) To prevent downstream flooding, the maximum flow to be released from the catchment is set at 180 m^3/s. Calculate the space needed to store the excess water from this event (in m^3) and plot hydrograph of the event. *(20 marks)*

Q5 (20 marks)

a) A catchment of are 0.25 km^2 is subjected to a storm with the following profile:

Time (hr)	1	2	3	4	5	6
Rain (mm)	7	18	25	12	10	3

If the volume of storm runoff is 8250m^3, estimate the φ −index (neglect the effect of ET)

(5 marks)

b) Suppose that the parameters for Horton's equation are $f_o = 3.5 mm/hr$, $f_c = 0.6\ mm/hr$ and $k = 4.1\ hr^{-1}$. Determine the infiltration rates after *0, 10 min, 20 min, 1 hr, 1.5 hr* and *2 hr* and the cumulative infiltration after 2 hours. Assume continuously ponded conditions. *(10 marks)*

c) A 30 cm diameter well completely penetrates a confined aquifer of permeability 45 m/day. The length of the strainer is 20 m. Under steady state of pumping, the drawdown at the well was found to be 3.0 m and the radius of influence was 300 m, calculate the discharge. *(5 marks)*

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Relevant equations

Latent heat:

$$l_v = 2.5\times10^6 - 2370T \quad \text{(J/kg)}$$

Evaporation rate:

$$E_r = \frac{1}{l_v \rho_w}(R_n - H_s - G)$$

where
E_r is evaporation rate (m/s),
H_s is sensible heat flux (in W/m^2, to change liquid water temperature),
G is the ground heat flux (in W/m^{2,} to change underlying soil temperature),
R_n is the net radiation flux (W/m^2),
l_v is the latent heat of vapourisation (J/kg),
ρ_w is water specific density (kg/m^3).

Darcy's equation for saturated soil:

$$q = KS_f = K\frac{\Delta h}{\Delta s}$$

Pore velocity in soil:

$$V = \frac{q}{\eta}$$

Horton's equation:

$$f_t = f_c + (f_0 - f_c)e^{-kt}$$

Total infiltration in T hour period:

$$F = \int_0^T f_t dt = \int_0^T f_c + (f_0 - f_c)e^{-kt} dt$$

$$= f_c T + \frac{1}{k}(f_0 - f_c)\left(1 - e^{-kT}\right)$$

where
f_t is infiltration capacity at time t (mm/hr),
f_o is initial infiltration capacity (mm/hr),
f_c is final capacity (mm/hr),
k is empirical constant (hr^{-1})

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Yield of a well:

$$Q = \frac{\pi K\left(h_1^2 - h_0^2\right)}{\ln(r_1 / r_0)}$$ Unconfined aquifer

$$Q = \frac{2\pi bK\left(h_1 - h_0\right)}{\ln(r_1 / r_0)}$$ Confined aquifer

Unit hydrograph application:

The convolution formula for the unit hydrograph model is

$$Q_i = \sum_{m=1}^{n \le M} R_m U_{i-m+1}$$

where
R_m is effective rainfall,
U_i is unit hydrograph ordinates,
Q_i is direct runoff,
M is the number of rainfall values

River Flow Routing (The Muskingum Method):

The storage function in a river reach is linked with both inflow and outflow.

$$S = K\left[XI + (1 - X)O\right]$$

where K is the storage time constant for the reach, X is a weighing factor (between 0~ 0.5, usually around 0.2).

From water balance equation,

$$\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{S_2 - S_1}{\Delta t}$$

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$$O_2 = C_0 I_2 + C_1 I_1 + C_2 O_1$$

where $C_0 = (0.5\Delta t - KX)/D$, $C_1 = (KX + 0.5\Delta t)/D$, $C_2 = (K - KX - 0.5\Delta t)/D$

$D = K - KX + 0.5\Delta t$

Reservoir flow routing:

The storage function is given by

$$S = f(h)$$

The discharge over the spillway crest is a function of h as well.

$$O = Cbh^{1.5}$$

where

C is the discharge coefficient,

b is the width of the spillway crest.

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