	Organization Name: አዲስ አበባ ሳይንስና ቴክኖሎጂ ዩኒቨርሲቲ **ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY**	Document No.: VPAA/DPT/OF/030	
Title:	**FINAL EXAMINATION COVER PAGE**	Issue No. 1	Page No.: Page **1** of **18**

General Information

College: of Engineering **Department**: Civil Engineering
Course Name: Engineering Hydrology **Course Code**: CEng3108
Year: 3th **Semester**: 2nd

Final exam answer key

Part I: Matching (1 pt. each)

1. ***Ans. CATCHMENT/WATERSHED****: A watershed, also known as a catchment or drainage basin, is an area of land where all surface water converges to a single point, called an outlet. It is the land area that drains into the water body, encompassing not only the water channels but also the surrounding land that contributes to the water flow generated from every drop of rainfall to through the common outlet.*
2. ***Ans. PRECIPITATION****: - refers to any form of water particles that fall from the atmosphere and reach the Earth's surface. This includes rain, snow, sleet, hail, and drizzle. Generally, it's the process where water vapor in the air condenses and falls due to gravity.*
3. ***Ans. OROGRAPHIC PRECIPITATION****: - is a precipitation that occurs when moist air is forced to rise over a mountain or other topographic barrier, causing it to cool and condense, leading to precipitation on the windward side of the mountain. The mountain acts as a lift, causing the air to rise, cool, and release its moisture.*
4. ***Ans. CONVECTIVE PRECIPITATION****: - is a precipitation produced by rising, buoyant or less dense air parcels due to heating by the sun's energy that condense as they ascend, forming cumuliform clouds like cumulonimbus. It's characterized by showery precipitation with rapidly changing intensity and is often associated with localized, intense rainfall events.*
5. ***Ans. HYGROMETER****: - is a device used to measure humidity, which is the amount of water vapor in the air. It's used in various settings to monitor and control moisture levels for comfort, health, preservation, and industrial processes.*

Part II Multiple choice (2 pts. each)

1. **Ans. A.** *A unit hydrograph represents the direct runoff response of a drainage basin to a unit depth of rainfall excess (e.g., 1 inch or 1 cm or 1 mm) occurring uniformly over the basin at a constant rate for a specified duration (e.g., 2hr, or 6hr, or 12 hr, or 24 hr ...).*
2. **Ans. B.** *The double-mass curve is used to check the consistency of many kinds of hydrologic data including rainfall by comparing data for a single station with that of a pattern composed of the data from several other stations in the area. It can be used to adjust inconsistent precipitation data.*

3. **Ans. C.** *An S-curve hydrograph is primarily used to convert a unit hydrograph (UH) of one duration to a UH of a different duration. This is achieved by integrating an instantaneous unit hydrograph (IUH) derived from an impulse rainfall, which creates a continuously rising curve that eventually reaches a constant value.*

Part III Comprehension & discussion (2 pts each)

1. **A)** *Rainfall data consistency checks are crucial for ensuring the reliability of rainfall measurements over time, as inconsistencies can arise from various factors. These checks help identify and correct errors or biases introduced by changes in the measuring environment, instrument malfunctions, or observational procedures. Inconsistencies can significantly impact hydrological analyses, water resource management, and climate studies if not addressed properly before any analysis*. **B)** *Converting point rainfall data to areal rainfall (average rainfall over an area) is necessary because most hydrological and meteorological studies require rainfall information over a region, not just at a single point. Areal rainfall data is crucial for applications like flood prediction, water resource management, and agricultural planning, as it provides a more comprehensive picture of rainfall distribution and its impact on larger areas.*
2. **A)** *A watershed's water balance, also known as a water budget, is a fundamental hydrological concept that tracks the movement and storage of water within a defined area. It essentially represents the balance between water entering and leaving a watershed, including precipitation, runoff, evapotranspiration, and changes in water storage. Understanding this balance is crucial for managing water resources effectively. Breakdown of the key components of this ba;ance is:*

Inputs:

- ***Precipitation, P:*** *Water entering the watershed as rain, snow, or other forms of precipitation.*
- ***Groundwater discharge, G_i:*** *Water entering the watershed from underground aquifers.*

Outputs:

- ***Runoff, R:*** *Water flowing over the surface of the land, eventually reaching rivers and streams.*

- ***Evapotranspiration, ET:*** *Water returning to the atmosphere through evaporation from surfaces and transpiration from plants.*
- ***Sub-surface outflow, Q_i:*** *Water leaving the watershed through the sub-surface of the watershed to rivers and streams, also known as interflow.*
- ***Groundwater recharge, G_o:*** *Water leaving the watershed into underground aquifers.*

Change in storage, ΔS***:*** *The net gain or loss of water stored within the watershed, such as in lakes, reservoirs, or soil moisture.*

The water balance equation summarizes these components:

Precipitation + Groundwater discharge = Runoff + Evapotranspiration + Sub-surface outflow + Groundwater recharge + Change in Storage

Mathematically, $P + G_i = R + ET + Q_i + G_o + \Delta S$

b) A water balance for a water body is a method to track and account for all the inputs and outputs of water in a specific system over a defined period. It helps understand how water flows into, out of, and is stored within a water body. This analysis is crucial for managing water resources effectively and understanding the impact of various factors like climate and human activities on water availability. Components of a water balance for a water body:

Inflows:

- ***Water entering the water body****. This can include precipitation,* **P** *(rain, snow), surface runoff,* $\mathbf{Q_i}$*, from surrounding land, groundwater discharge,* $\mathbf{G_i}$*, into the water body, and any water piped or channeled,* $\mathbf{Q_p}$*, in from other sources.*

Outflows:

- ***Water leaving the water body****. This can include evaporation,* **E***, (water turning into vapor), surface outflow (rivers, streams),* Q_o*, groundwater outflow,* G_o*, and any water taken out for human use,* Q_h*, (irrigation, industrial use).*

Change in Storage*:*

- ***The difference between the total water entering and the total water leaving the water body system,*** ΔS*. This represents the net change in the water volume within the water body over the specific time period. A positive change in storage indicates a rise in water level, while a negative change indicates a drop.*

Water balance equation*: Inflows = Outflows + Change in Storage*

Mathematically, $P + Q_i + G_i + Q_p = R + E + Q_o + G_o + Q_h + \Delta S$

3. *Baseflow separation methods aim to isolate the groundwater contribution (baseflow) from the total streamflow, which also includes surface runoff and interflow. Several techniques exist, broadly categorized as graphical and digital filter methods. Graphic methods, like the straight line and two-line methods, involve visually identifying and connecting baseflow components on a hydrograph. Digital filter methods, such as the Constant Method (CM) and master recession, utilize mathematical algorithms to separate baseflow based on streamflow data.*

4. *Design life, risk of failure, and design period are crucial concepts in engineering and construction. Design life refers to the expected duration a structure or component is intended to function as designed. Risk of failure is the probability that the structure or component will not meet its intended function within the design life. The design period is the timeframe over which the structure's performance is evaluated to ensure it meets the required reliability.*

With examples:

- ***Design Life:*** *A bridge might have a design life of 100 years, meaning it's expected to function as designed for that period.*
- ***Risk of Failure:*** *10% chance of failure over the design life due to material properties, environmental conditions, and usage patterns influence the risk of failure.*
- ***Design Period:*** *This is the timeframe used in calculations to determine the appropriate design parameters for a structure. It is often related to the design life, but can also consider other factors like the return period of extreme events.*

Relationship between these concepts:

- *The design period is used to determine the acceptable risk of failure over the design life.*
- *A longer design life typically requires a lower acceptable risk of failure, leading to potentially higher construction costs.*
- *Engineers need to balance the desired design life, acceptable risk of failure, and construction costs to arrive at an optimal design*

- *Urban and rural hydrology differ significantly due to human impact on the landscape. Urban areas, with their impervious surfaces, experience faster and more voluminous runoff, leading* *to higher peak flows and shorter lag times compared to rural areas where water infiltrates more readily into the soil and groundwater.*

Rural Hydrology is represented by:

- *Natural landscapes,*
- *Slower runoff.*
- *More sustained baseflow:*
- *Gentler hydrographs***:**

Urban Hydrology:

- *Impervious surfaces:*
- *Increased runoff:*
- *Higher peak flows:*
- *Shorter lag time:*
- *Reduced baseflow reduction:*

Part IV-Workouts

#1. Ans

Step-1. Check whether normal ratio is the appropriate method:

The ***normal ratio method*** *is used to estimate missing precipitation data when the normal annual precipitation at any of the surrounding stations differs from the normal annual precipitation at the station in question by more than 10%.*

Let's check this condition:

- Normal annual rainfall at station D (N_D) = 890 mm
- 10% of P_D = 0.10 * 890 = 89 mm

We compare the normal rainfall of stations A, B, and C to that of station D:

- $|N_A - N_D| = |750 - 890| = 140$ mm (which is > 89 mm)
- $|N_B - N_D| = |840 - 890| = 50$ mm (which is < 89 mm)
- $|N_C - N_D| = |720 - 890| = 170$ mm (which is > 89 mm)

Since the normal rainfall at stations A and C differs from station D by more than 10%, the Normal Ratio Method is the correct procedure to use.

Step-2. State the Formula

The formula for the Normal Ratio Method is:

$$Px = (1/n) * \Sigma [(Nx / Ni) * Pi]$$

Where:

- **P_x** = Estimated rainfall at the station with missing data (Station D)
- **N_x** = Normal annual rainfall at the station with missing data (Station D)
- **P_i** = Recorded storm rainfall at a surrounding station (A, B, or C)
- **N_i** = Normal annual rainfall at that surrounding station (A, B, or C)
- **n** = Number of surrounding stations used (in this case, 3)

Applying this to our specific problem:

$P_D = (1/3) * [(N_D / N_A) * P_A + (N_D / N_B) * P_B + (N_D / N_C) * P_C]$

Step-3. List the given data

- Station A: $P_A = 80$ mm, $N_A = 750$ mm
- Station B: $P_B = 70$ mm, $N_B = 840$ mm
- Station C: $P_C = 90$ mm, $N_C = 720$ mm
- Station D: $P_D = ?$, ND = 890 mm

Step-4. Substitute and calculate

$P_D = (1/3) * [(890 / 750) * 80 + (890 / 840) * 70 + (890 / 720) * 90]$
$P_D = (1/3) * [94.93 + 74.17 + 111.25]$
$P_D = (1/3) * [280.35]$
$\underline{P_D = 93.45 \text{ mm}}$

The estimated storm rainfall at station D, calculated using the Normal Ratio Method, is **93.45 mm**.

#2 Ans.

Step 1: Calculate the Total Area (A)

The total area of the watershed is the sum of the areas of its different land uses. The Rational Method formula, $Q = \frac{C * I * A}{360}$, requires the area in hectares (ha).

- Cultivated area = 3.5 km²
- Forest area = 2.5 km²
- Residential area = 2.0 km²

Total Area (A) in km²: A = 3.5 + 2.5 + 2.0 = **<u>8.0 km²</u>** -------------------- #

Convert Area to Hectares: Since 1 km² = 100 ha: A = 8.0 km² * 100 ha/km² = **<u>800 ha</u>**--- #

Step 2: Calculate the Weighted Runoff Coefficient (C)

The watershed has multiple land uses with different runoff coefficients (c). We need to calculate a weighted average runoff coefficient (C_w) for the entire watershed.

The formula is: $C_w = (\Sigma [C_i * A_i]) / A_{total}$

- $C_{cultivated} = 0.2$
- $C_{forest} = 0.1$
- $C_{residential} = 0.85$

Calculation:

$C_w = [(0.2 * 3.5\ km^2) + (0.1 * 2.5\ km^2) + (0.85 * 2.0\ km^2)] / 8.0\ km^2$
$C_w = [0.70 + 0.25 + 1.70] / 8.0$
$C_w = 2.65 / 8.0$
Cw = 0.33125-------------------- #

Step 3: Calculate the time of concentration (t_c)

The time of concentration (t_c) is the time it takes for water to travel from the most hydrologically distant point in the watershed to the outlet. We will use the provided Kirpich modified formula.

Formula: $t_c = 0.02 * L^{0.8} * S^{-0.4}$

Where:

- t_c = time of concentration in **minutes**
- L = length of the watercourse in **meters**
- S = slope of the watercourse (dimensionless)

Given Data:

- Length of watercourse = 2 km = **2000 m**
- Fall in elevation = 50 m

Calculate Slope (S):

S = (Fall in elevation) / (Length of watercourse)
S = 50 m / 2000 m = **0.025** -------------------- #

Calculate t_c:

$t_c = 0.02 * (2000)^{0.8} * (0.025)^{-0.4}$
$t_c = 0.02 * (435.27) * (3.640)$
$t_c = 8.705 * 3.640$
t_c = 31.68 minutes -------------------- #

Step 4: Calculate the Rainfall Intensity (I)

Rainfall intensity (I) is calculated using the given Intensity-Duration-Frequency (IDF) relationship, where the duration is equal to the time of concentration (t_c).

IDF Formula: $I = (800 * T^{0.2}) / (t_c + 12)^{0.5}$

Where:

- I = rainfall intensity in **mm/hr**
- T = return period in **years**
- t_c = time of concentration in **minutes**

Given Data:

- Return Period (T) = **50 years**
- Time of Concentration (t_c) = **31.68 min**

Calculation:

$I = (800 * 50^{0.2}) / (31.68 + 12)^{0.5}$
$I = (800 * 2.1867) / (43.68)^{0.5}$
$I = 1749.36 / 6.609$
I = 264.69 mm/hr -------------------- #

Step 5: Calculate the Design Discharge (Q)

Now we have all the components for the Rational Method formula.

Formula: $Q = (C * I * A) / 360$

Where:

- Q = design discharge in **m³/s**
- C = weighted runoff coefficient (dimensionless) = **0.33125**
- I = rainfall intensity in **mm/hr** = **264.69 mm/hr**
- A = watershed area in **hectares** = **800 ha**

Calculation:

$Q = (0.33125 * 264.69 * 800) / 360$
$Q = 70130 / 360$
Q = 194.8 m³/s -------------------- #

Final Answer: The estimated design discharge for the 50-year return period is **194.8 m³/s**.

#3 Ans.

To route the given flood hydrograph through the channel reach using the Muskingum routing equation and determine the outflow hydrograph.

Step 1: Understand the Muskingum Method

The Muskingum method uses the following routing equation:

$\mathbf{Q_2 = C_0 * I_2 + C_1 * I_1 + C_2 * Q_1}$

Where:

- $\mathbf{Q_2}$ = Outflow at the end of the current time step (what we want to find)
- $\mathbf{Q_1}$ = Outflow at the start of the current time step (the previous Q_2)
- $\mathbf{I_2}$ = Inflow at the end of the current time step
- $\mathbf{I_1}$ = Inflow at the start of the current time step
- $\mathbf{C_0, C_1, C_2}$ = Routing coefficients that depend on the channel properties (K, X) and the time step (Δt).

Step 2: List Given Data and Calculate Routing Coefficients

Given Data:

- Storage-time constant (K) = **20 hours**
- Weighing factor (X) = **0.32**
- Time step (Δt) = **6 hours** (from the hydrograph table)

Formulas for the coefficients: The coefficients are calculated as follows:

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

Calculation: First, calculate the common denominator (D):

D = 20 - (20 * 0.32) + (0.5 * 6)
D = 20 - 6.4 + 3
D = 16.6

Now, calculate the coefficients:

$C_0 = (-(20 * 0.32) + (0.5 * 6)) / 16.6 = (-6.4 + 3) / 16.6 = -3.4 / 16.6 = \mathbf{-0.2048}$
$C_1 = ((20 * 0.32) + (0.5 * 6)) / 16.6 = (6.4 + 3) / 16.6 = 9.4 / 16.6 = \mathbf{0.5663}$
$C_2 = (20 - (20 * 0.32) - (0.5 * 6)) / 16.6 = (20 - 6.4 - 3) / 16.6 = 10.6 / 16.6 = \mathbf{0.6386}$

Verification Check: The sum of the coefficients should be equal to 1.

$C_0 + C_1 + C_2 = -0.2048 + 0.5663 + 0.6386 = \mathbf{1.0001}$ (This is correct, the small difference is due to rounding).

Step 3: Perform the routing calculation

We will create a table to systematically calculate the outflow hydrograph (Q) at each time step.

Initial Assumption: For the first-time step (t=0), we assume the flow is steady, so the initial outflow is equal to the initial inflow.

$Q(t=0) = I(t=0) = 36\ m^3/s$-------------------- #

The routing calculation for each subsequent step is:

$Q_2 = (-0.2048 * I_2) + (0.5663 * I_1) + (0.6386 * Q_1)$

The detailed routing table is shown below.

Where, **$Q_n = C_0 * I_n + C_1 * I_{n-1} + C_n * Q_{n-1}$**

Time (hr)	Inflow I (m^3/s)	$C_0 * I_2$	$C_1 * I_1$	$C_2 * Q_1$	Outflow Q_n (m^3/s)
0	**36**	-	-	-	**36.00**
6	**30**	-6.14	20.40	22.99	**37.25**
12	**50**	-10.24	16.99	23.79	**30.54**
18	**75**	-15.36	28.32	19.50	**32.46**
24	**90**	-18.43	42.47	20.73	**44.77**
30	**102**	-20.89	50.97	28.59	**58.67**
36	**88**	-18.02	57.76	37.47	**77.21**
42	**70**	-14.34	49.83	49.31	**84.80**
48	**60**	-12.29	39.64	54.16	**81.51**
54	**48**	-9.83	33.98	52.06	**76.21**
60	**36**	-7.37	27.18	48.67	**68.48**

Conclusion: The outflow hydrograph

The derived outflow hydrograph is presented in the final column of the table above.

Final Outflow Hydrograph:

Time (hr)	Outflow Q (m³/s)
0	36.00
6	37.25
12	30.54
18	32.46
24	44.77
30	58.67
36	77.21
42	**84.80**
48	81.51
54	76.21
60	68.48

The routing process has attenuated the peak flow (from a peak inflow of 102 m³/s to a peak outflow of ~84.8 m³/s) and delayed it (the inflow peak was at t=30 hr, while the outflow peak is at t=42 hr).

#4 Ans.

Step-1: Estimate the flood discharge (Q_T): The design flood discharge for a given return period (T) using Gumbel's method is calculated with the following formula:

$Q_T = \bar{x} + K_T * \sigma$

Where:

- Q_T = Flood discharge for return period T
- $\bar{x}$ = Mean of the annual flood discharges
- σ = Standard deviation of the annual flood discharges
- K_T = Gumbel frequency factor

The frequency factor K_T is calculated as: $K_T = (Y_T - \bar{y}_n) / S_n$

Where:

- Y_T = Reduced variate for return period T
- $\bar{y}_n$ = Reduced mean (depends on sample size n)
- S_n = Reduced standard deviation (depends on sample size n)

Step 2: Determine given values and sample size (n)

- Mean ($\bar{x}$) = **29,600 m³/s**
- Standard Deviation (σ) = **14,860 m³/s**
- Return Period (T) = 50 years (equal to the expected life of the structure)
- Sample Period = 1948 to 1979
- Sample Size (n) = (1979 - 1948) + 1 = **32 years** ------------#

Step 3: Calculate the Reduced Variate (Y_T)

- $Y_T = -\ln[-\ln(1 - 1/T)]$
  $Y_T = -\ln[-\ln(1 - 1/50)]$
  $Y_T = -\ln[-\ln(0.98)]$
  $YT = -\ln(0.0202)$
  $Y_T \approx 3.90$ ------------#

Step 4: Find reduced mean ($\bar{y}_n$) and reduced standard deviation (S_n)

These values are dependent on the sample size (n=32) and are taken from standard Gumbel's distribution tables given on the exam questions (Table 3) (from Chow's Handbook of Applied Hydrology).

For **n = 32**:

- Reduced mean ($\bar{y}_n$) = **0.5380**

- Reduced standard deviation (S_n) = **1.1197**

Step 5: Calculate the Gumbel Frequency Factor (K_T)

- $K_T = (Y_T - \bar{y}_n) / S_n$
  $K_T = (3.90 - 0.5380) / 1.1197$
  $K_T = 3.362 / 1.1197$
  $K_T \approx 3.003$ ------------#

Step 6: Calculate the 50-Year Flood Discharge (Q_{50})

Now, substitute all the values back into the main Gumbel equation:

- $Q_{50} = \bar{x} + K_T * \sigma$
  $Q_{50} = 29,600 + (3.003 * 14,860)$
  $Q_{50} = 29,600 + 44,625$
  $Q_{50} = 74,225\ m^3/s$ ------------#

Answer for Part A: The estimated flood discharge for a 50-year return period is **74,225 m^3/s**.

Part B: Calculate the 50% confidence limit

The confidence limits for a Gumbel estimate are calculated as:

Confidence Limits = $Q_T \pm f(c) * S_e$

Where:

- **f(c)** = A factor that depends on the confidence level (given as 0.674 for 50%).
- **S_e** = The standard error of the estimate.

The standard error **S_e** is calculated with the formula:

$S_e = \sigma * \sqrt{[(1 + 1.3K_T + 1.1K_T^2) / n]}$

Step 1: Calculate the Standard Error (S_e)

Using the values, we've already found:

- $\sigma = 14,860\ m^3/s$
- K_T = 3.003
- n = 32

$S_e = 14,860 * \sqrt{[(1 + (1.3 * 3.003) + (1.1 * (3.003)^2)) / 32]}$
$S_e = 14,860 * \sqrt{[(1 + 3.904 + (1.1 * 9.018)) / 32]}$
$S_e = 14,860 * \sqrt{[(1 + 3.904 + 9.920) / 32]}$
$S_e = 14,860 * \sqrt{[14.824 / 32]}$
$S_e = 14,860 * \sqrt{[0.46325]}$

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$S_e = 14{,}860 * 0.6806$

$S_e \approx 10{,}113\ m^3/s$ ------------#

Step 2: Calculate the confidence interval

Now, we can find the upper and lower bounds of the confidence interval.

Margin of Error = f(c) * S_e = 0.674 * 10,113 = **6,816 m^3/s** ------------#

- **Upper Confidence Limit:**

  $Q_{upper} = Q_{1/2} = Q_{50}$ + 6,816 = 74,225 + 6,816 = **81,041 m^3/s** ------------#

- **Lower Confidence Limit:**

  $Q_{lower} = Q_{2/2} = Q_{50}$ - 6,816 = 74,225 - 6,816 = **67,409 m^3/s** ------------#

Answer for Part B: The 50% confidence limits for the flood discharge are between **67,409 m^3/s** and **81,041 m^3/s**. This means there is a 50% probability that the true 50-year flood discharge lies within this range.

#5 Ans.

*This problem is solved using the **Mass Curve Method**, which can be done numerically using a table. The goal is to find the maximum cumulative deficit over a repeating cycle, which represents the minimum required reservoir storage. Here is the detailed step-by-step solution.*

Step 1: Define the Objective and Method

The objective is to find the minimum storage capacity of a reservoir required to meet a constant demand of 7 m^3/s, given the mean monthly inflows. We will use a tabular numerical analysis, which is the practical application of the graphical mass curve method. The analysis must be run for two consecutive identical years (24 months) to correctly capture any deficit that carries over from the end of one year to the beginning of the next.

Step 2: Convert Flow Rates to Monthly Volumes

First, we need to convert all flow rates (in m^3/s) into volumes (in m^3 or Million m^3) for each month.

The problem states to assume every month has 30 days.

- **Seconds per month** = 30 days/month × 24 hours/day × 60 min/hour × 60 sec/min

  = **2,592,000 seconds**

The volume is calculated as:

Volume (m^3) = Flow Rate (m^3/s) × 2,592,000 s ---------------#

To make the numbers more manageable, we will work with volumes in "Million cubic meters (Mm^3)". i.e. **Volume (Mm^3) = Flow Rate (m^3/s) × 2.592**

Step 3: Calculate the monthly demand volume

The demand is a constant rate of 7 m^3/s.

- **Monthly Demand Volume** = 7 m^3/s × 2.592 $Mm^3/m^3/s$ = **18.144 Mm^3 ---------------#**

  This demand volume is the same for every month.

Step 4: Create the Mass Curve Analysis Table

We will now create a table to track the surplus or deficit each month and calculate the cumulative deficit. The analysis is run for 24 months.

Month	Inflow (Q) (m^3/s)	Inflow Volume (V_{in}) (Mm^3)	Demand Volume (V_d) (Mm^3)	Monthly Surplus / Deficit ($V_{in} - V_d$)	Cumulative Surplus / Deficit (Mm^3)
Jan	5	12.960	18.144	-5.184	-5.184
Feb	8	20.736	18.144	2.592	-2.592
Mar	12	31.104	18.144	12.960	10.368
Apr	10	25.920	18.144	7.776	18.144
May	7	18.144	18.144	0.000	18.144
Jun	4	10.368	18.144	-7.776	10.368
Jul	2	5.184	18.144	-12.960	-2.592
Aug	1	2.592	18.144	-15.552	-18.144
Sep	3	7.776	18.144	-10.368	-28.512
Oct	6	15.552	18.144	-2.592	-31.104
Nov	9	23.328	18.144	5.184	-25.920
Dec	11	28.512	18.144	10.368	-15. 552

Jan (Y_2)	5	12.960	18.144	-5.184	-20.736
Feb (Y_2)	8	20.736	18.144	2.592	-18.144
Mar (Y_2)	12	31.104	18.144	12.960	-5.184
Apr (Y_2)	10	25.920	18.144	7.776	2.592
May (Y_2)	7	18.144	18.144	0.000	2.592
Jun (Y_2)	4	10.368	18.144	-7.776	-5.184
Jul (Y_2)	2	5.184	18.144	-12.960	-18.144
Aug (Y_2)	1	2.592	18.144	-15.552	-33.696
Sep (Y_2)	3	7.776	18.144	-10.368	**-44.064**
Oct (Y_2)	6	15.552	18.144	-2.592	-46.656
Nov (Y_2)	9	23.328	18.144	5.184	-41.472
Dec (Y_2)	11	28.512	18.144	10.368	-31.104

Step 5: Determine the Minimum Required Storage

The minimum storage required is the **maximum cumulative deficit** found in the "Cumulative Surplus / Deficit" column. This value represents the largest amount of water that must be drawn from storage to meet the demand when inflows are insufficient.

From the table, the lowest value in the cumulative deficit column is **-46.656 Mm³** at the end of October in the second year.

*Correction: After reviewing the table calculations carefully, the maximum cumulative deficit actually occurs at the end of October (Year 2), not September. Let's verify the calculation for October (Y2):

- Cumulative at end of Sep (Y2) = -44.064
- Deficit in Oct (Y2) = -2.592
- Cumulative at end of Oct (Y2) = -44.064 + (-2.592) = **-46.656 Mm³**
  This is the lowest point.

The required storage is the absolute value of this maximum deficit.

Required Storage = |-46.656 Mm³| = **46.656 Million m³**

Conclusion

The minimum storage required to maintain a constant demand rate of 7 m³/s without failure is **46,656,000 m³**.

Given formula and tables

$$y_T = -[\ln . \ln \tfrac{T}{T-1}]$$

$$K = \frac{y_T - \overline{y_n}}{s_n}$$

$$x_T = \bar{x} + K\sigma_x$$

$$x_{1/2} = x_T \pm f(c) * S_e$$

$$S_e = \text{probable error} = b\frac{\sigma_{n-1}}{\sqrt{N}}$$

$$b = \sqrt{1 + 1.3K + 1.1K^2}$$

$$C_1 = \frac{\Delta t + 2Kx}{\Delta t + 2K - 2Kx}$$

$$C_2 = \frac{\Delta t - 2Kx}{\Delta t + 2K - 2Kx}$$

$$C_3 = \frac{-\Delta t + 2k - 2KX}{\Delta t + 2k - 2kx}$$

Table 1 Values for reduced variates and reduced standard deviation

N	0	1	**2**	3	4	5	6	7	8	9
10	0.4952	0.4996	0.5035	0.507	0.51	0.5128	0.5157	0.5181	0.5202	0.522
20	0.5236	0.5252	0.5268	0.5283	0.5296	0.5309	0.532	0.5332	0.5343	0.5353
30	0.5362	0.5371	**0.538**	0.5388	0.5396	0.5402	0.541	0.5418	0.5424	0.543
40	0.5436	0.5442	0.5448	0.5453	0.5458	0.5463	0.5468	0.5473	0.5477	0.5481
50	0.5485	0.5489	0.5493	0.5497	0.5501	0.5504	0.5508	0.5511	0.5515	0.5518
60	0.5521	0.5524	0.5527	0.553	0.5533	0.5535	0.5538	0.554	0.5543	0.5545
70	0.5548	0.555	0.5552	0.5555	0.5557	0.5559	0.5561	0.5563	0.5565	0.5567
80	0.5569	0.557	0.5572	0.5574	0.5576	0.5578	0.558	0.5581	0.5583	0.5585
90	0.5586	0.5587	0.5589	0.5591	0.5592	0.5593	0.5595	0.5596	0.5598	0.5599
100	0.56									

Reduced mean $\boldsymbol{Y}_n$ in Gumbel's extreme value distribution, N = sample size

N	0	1	**2**	3	4	5	6	7	8	9
10	0.9496	0.9676	0.9833	0.9971	1.0095	1.0206	1.0316	1.0411	1.0493	1.0565
20	1.0628	1.0696	1.0754	1.0811	1.0864	1.0915	1.0961	1.1004	1.1047	1.1086
30	1.1124	1.1159	**1.1193**	1.1226	1.1255	1.1285	1.1313	1.1339	1.1363	1.1388
40	1.1413	1.1436	1.1458	1.148	1.1499	1.1519	1.1538	1.1557	1.1574	1.159
50	1.1607	1.1623	1.1638	1.1658	1.1667	1.1681	1.1696	1.1708	1.1721	1.1734
60	1.1747	1.1759	1.177	1.1782	1.1793	1.1803	1.1814	1.1824	1.1834	1.1844
70	1.1854	1.1863	1.1873	1.1881	1.189	1.1898	1.1906	1.1915	1.1923	1.193
80	1.1938	1.1945	1.1953	1.1959	1.1967	1.1973	1.198	1.1987	1.1994	1.2001
90	1.2007	1.2013	1.202	1.2026	1.2032	1.2038	1.2044	1.2049	1.2055	1.206
100	1.2065									

Reduced standard deviation S_n in Gumbel's extreme value distribution, N = sample size

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