PROBLEM SOLVING: ENGINEERING HYDROLOGY

2024

SITI NUR FARHANA BINTI ABDUL AZIZ
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First Edition

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PREFACE

This book was created for learning and teaching purposes of basic hyrological course. In this edition, material was presented interactively as an aid to learn concept of hydrology with detail elaboration on hydrological problem solving accompanied by drawing and activities in order to supply the optimal information and knowledge to the reader.

This book comprises of 5 chapters. All notes and example were presented with clear explanation and interesting format to prevent bored in learning and teaching processes. Each topics were divided with a different colours theme to ease the user.

Any feedback and suggestion is welcomed to improve the quality of this book in future. It is very pleased that this book could assist the reader and user especially students and lecturer as an alternative reference sources to enhance knowledge in Hydrology.

Thank you.

Regards,

Farhana Aziz

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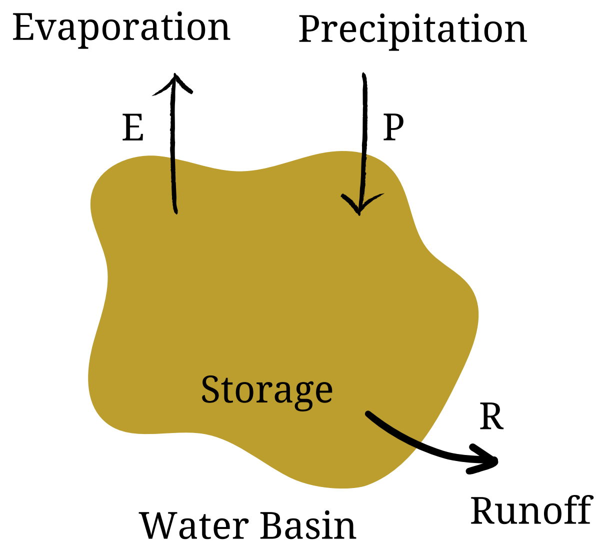
INTRODUCTION TO HYDROLOGY

Author: SITI NUR FARHANA BINTI ABDUL AZIZ



COMPONENTS OF WATER CYCLE

INFLOW, I

- **PRECIPITATION** over the catchment and reservoir
- **LATERAL FLOW:** Surface or groundwater flow from other catchment areas

OUTFLOW, O

- Surface **EVAPORATION**
- **GROUNDWATER SEEPAGE**
- **DIRECT RUNOFF** : water taken for irrigation or to spillways to producing power

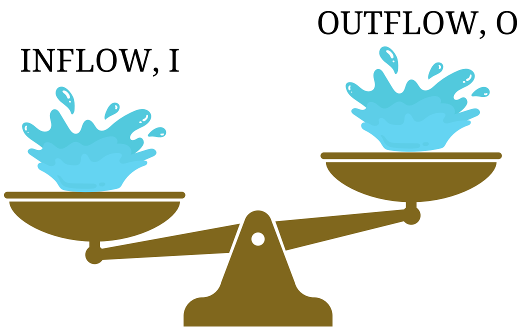
Paddy field receive the most water irrigation from water storage in Malaysia.

ACTIVITY 1

Watch how paddy field receive water from irrigation

Can you guess how many water used as an irrigation to paddy field in Malaysia?

WATER BALANCE EQUATION



Total volume inflow – Total volume outflow = Total change in volume of the system

∑ volume inflow – ∑ volume outflow = ∑ change in volume of the system

$$I - O = \frac{\Delta S}{\Delta t} \qquad (1)$$

Based on the table of components of water system in page 2,

Inflow Process, I → Precipitation, P

Outflow Process, O → Runoff, R
Loss due to infiltration, F
Loss due to interception, Li
Loss due to evaporation, Le

Thus, equation 1 will be;

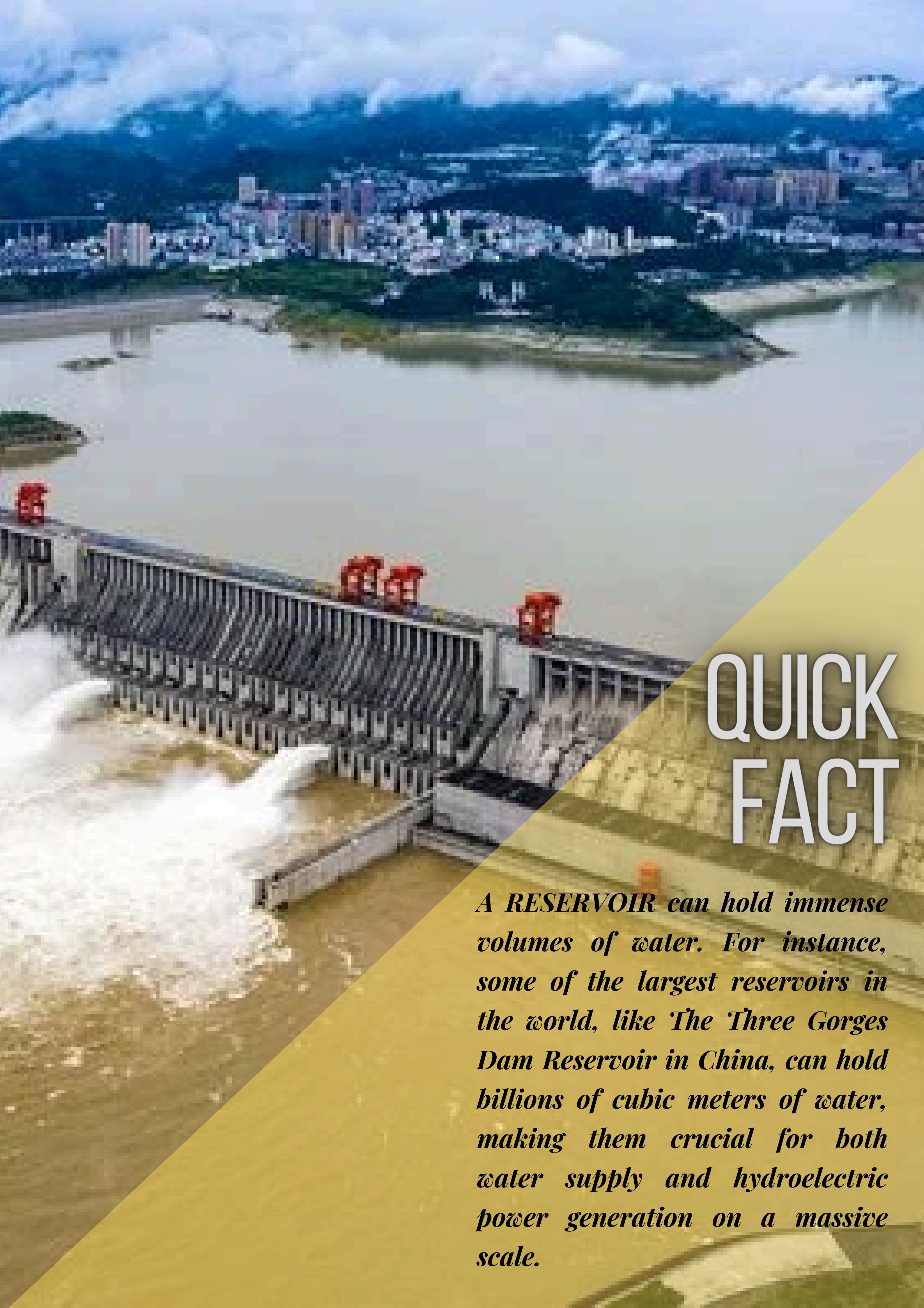
$$\mathbf{P - (R + Li + Le + F) = \Delta S} \qquad (2)$$

Note that,
ΔS is change in storage
Li, Le, F and ΔS are considered losses and noted as L

Thus, equation 2 will be;

$$P - R = L$$

$$\mathbf{R = P - L} \qquad (3)$$



QUICK FACT

A RESERVOIR can hold immense volumes of water. For instance, some of the largest reservoirs in the world, like The Three Gorges Dam Reservoir in China, can hold billions of cubic meters of water, making them crucial for both water supply and hydroelectric power generation on a massive scale.

EXAMPLE 1.1

Based on observation, the flowrate that enter Malim Reservoir in a certain season is 350 m^3/s. If the outflow from the reservoir including infiltration and evaporation losses is 265 m^3/s, calculate the change in storage for 14 days.

Solution

List of information and intended question;

I = 350 m^3/s
O = 265 m^3/s
Δt = 14 days
ΔS = ?

Based on the information and intended question
--> Use equation 1 to answer this question.

$$I - O = \frac{\Delta S}{\Delta t}$$

$$350 - 265 = \frac{\Delta S}{\Delta t}$$

$$\frac{\Delta S}{\Delta t} = 85 \text{ m}^3/\text{s}$$

To obtain change in storage (ΔS),
-- > Eliminate Δt by multiple 85 m^3/s with the given duration;

$$\Delta S = 85 \frac{\text{m}^3}{\text{s}} \; x \; \Delta t$$

From the question, the given unit for duration is in day.
--> Convert Δt to second (s)

$$\Delta t = 14\ \cancel{\text{days}} \times \frac{24\ \cancel{h}}{1\ \cancel{day}} \times \frac{60\ \cancel{min}}{1\ \cancel{h}} \times \frac{60\ s}{1\ \cancel{min}}$$

$$\Delta t = 1209600\ \text{s}$$

So,

$$\Delta S = 85\,\frac{\text{m}^3}{\text{s}}\ x\ \Delta t$$

$$\Delta S = 85\,\frac{\text{m}^3}{\text{s}}\ x\ 1209600\ s$$

$$\underline{\boldsymbol{\Delta S = 102,816,000\ \text{m}^3}}$$

ACTIVITY 2

Watch online for Face-To-Face tutorial

EXAMPLE 1.2

Estimate the evaporation loses for the area in cm/yr if the drainage area given is 2.59 x 10^{10}m^2, the mean annual runoff is 19.82 m^3/s and the average annual rainfall is 20cm.

Solution

Note: This question is a little tricky. You need to understand the unit and term used in the question really well.

Mean annual runoff, average annual rainfall and cm/year; these three units refer to average of the process **ANNUALLY.**

List of information and intended question;

Drainage Area, A = 2.59 x 10^{10}m^2
Mean annual runoff, R = 19.82 m^3/s
Average annual rainfall, P = 20 cm
Losses due to evaporation, Le = ? cm/year

Based on the information and intended question,
--> Use equation 3 to answer the question.

$$\mathbf{R = P - L}$$

Rearrange the equation and let L be on the left side of equation.

$$\mathbf{L = P - R}$$

All value must have the same unit.
From the information given, R and P have two different unit.

Note here that value of P is given as **ANNUALLY.** So, P = 20cm/yr. This unit do not have to be changed as it is the same unit with the final answer.

$$R = 19.82\ \frac{m^3}{\cancel{s}} \times \frac{60\ \cancel{s}}{1\ \cancel{min}} \times \frac{60\ \cancel{min}}{1\ \cancel{hr}} \times \frac{24\ \cancel{hr}}{1\ \cancel{d}} \times \frac{365\ \cancel{d}}{1\ yr}$$

$$R = 625043520\ m^3/yr$$

$$R = \frac{625043520\ \frac{m^3}{yr}}{2.59 \times 10^{10}\ m^2}$$

$$R = 0.024\ m/yr$$

Change R in m/yr to R in cm/yr,

$$R = 0.024\ \frac{m}{yr} \times \frac{100\ cm}{1\ m}$$

$$R = 2.4\ cm/yr$$

So,

$$L = P - R$$

$$L = 20\ cm/yr - 2.4\ cm/yr$$

$$\underline{\mathbf{L = 17.6\ cm/yr}}$$

ACTIVITY 3

Watch online for Face-To-Face instruction

ACTIVITY 4

In the next two months, Johor Bharu District has received rainfall of 265 mm. Evaporation is estimated at 75 mm and infiltration into the subsurface by 25 mm. Calculate the volume of runoff to be stored in the reservoir if the catchment area is 80 km^2.

Solution

ACTIVITY 4

PLEASE ANSWER THIS TOGETHER WITH YOUR LECTURER

The hydrological continuity equation states that for a given time interval, difference of inflow to and outflow from a system is equal to change of storage of the system.

The hydrological continuity equation can be expressed as:

$$\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{\Delta S}{\Delta t} \quad (4)$$

Where,

I_1, I_2 = Rate of inflow before and after a changes

O_1, O_2 = Rate of outflow before and after a changes

ΔS = Change of storage, m³

Δt = Change of time, s

Total change in storage can be calculate using:

$$\Delta S = \frac{\Delta S}{\Delta t} \; x \; \Delta t \quad (5)$$

Total change in storage also can be calculate using this formula:

$$\Delta S = S_2 - S_1 \quad (6)$$

Where,

S_1 = Volume of storage at the beginning of a period

S_2 = Volume of storage at the end of a period

EXAMPLE 1.3

The recorded inflow and outflow for a reservoir A is 15 m^3/s and 20 m^3/s respectively. After a series of rainfall for a certain period, the recorded inflow and outflow increase to 20 m^3/s and 21 m^3/s respectively. If the initial water storage is 15 x 10^3 m^3, calculate the rate of change of storage and the new storage of water in the reservoir after one hour.

Solution

I_1 = 15m^3/s
O_1= 20m^3/s
I_2 = 6 m^3/s
O_2 = 6.5 m^3/s
S_1 = 15 x 10^3 m^3
$\frac{\Delta S}{\Delta t}$ = ?
S_2 = ?

Based on the information and intended question, you should use equation 4 to answer this question.

$$\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{\Delta S}{\Delta t} \quad (4)$$

$$\frac{15 + 6}{2} - \frac{20 + 6.5}{2} = \frac{\Delta S}{\Delta t}$$

$$10.5 - 13.25 = \frac{\Delta S}{\Delta t}$$

$$\frac{\Delta S}{\Delta t} = -2.75\, m^3/s$$

EXAMPLE 1.4

Kundasang's Lake with an area of $55km^2$ had a water elevation of 110m at the beginning of a certain month. In that month, the lake received an inflow of 6 m^3/s and outflow of $6.5m^3/s$. the lake also received a rainfall of 145mm and the rate of evaporation was estimated to be 70mm. based on the information given, calculate:

a) Total inflow at the end of month, I
b) Total outflow at the end of month, O
c) Change in storage at the end of month.

Solution

$A = 55km^2$
$H = 110m$
$\Delta t = 30days$

$I_1 = 6\ m^3/s$
$O = 6.5\ m^3/s$
$Le = 70mm$
$P = 145mm$

To understand this question, firstly, you have to identify all the information gave in the question, you must also understand the intention of the question.

From the information, we can assume that the following equation will be used:

$\sum$ volume inflow – $\sum$ volume outflow = $\sum$ change in volume of the system

$$\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{\Delta S}{\Delta t} \quad (4)$$

Based on this equation, we can divide the equation into THREE (3) different parts.

a) $\sum$ volume inflow = $\frac{I_1 + I_2}{2}$

b) $\sum$ volume outflow = $\frac{O_1 + O_2}{2}$

c) $\sum$ change in volume of the system = $\frac{\Delta S}{\Delta t}$

Thus, all the question can be answered using equation 4.

Answer for Question a)

$\sum$ volume inflow = $\frac{I_1 + I_2}{2}$

Information need:
$I_1 = 6\ m^3/s$
$P = 145mm = I_2$

To use this equation, both I_1 and I_2 must have the same unit. Thus, you have to change one of the units.

Let P = 145 mm change to m^3/s

- **Step 1: Change mm $\longrightarrow$ m**

$165\ mm = 165\ mm \times \frac{1\ m}{1000\ mm}$
$= 0.165\ m$

- **Step 2: Convert m $\longrightarrow$ m³**

To change m to m^3 , you have to multiple m to a variable with unit of m^2. If you look at the given information, you will find Area with km^2 unit. You must first change km to m

$A = 55 \times 10^6 m^2$

$P = I_2 = 0.165\ m \times 55 \times 10^6\ m^2$
$= 9.075 \times 10^6 m^3$

- **Step 3: Convert $m^3 \longrightarrow m^3/s$**

To convert m^3 to m^3/s, you have to divide m with variable with unit of s. If you look at the given information, you will find time with days as unit. You must first change days to second.

$$\Delta t = 30 \text{ days x } \frac{24 \text{ hours}}{1\ day} \ x \ \frac{60 \text{ minutes}}{1\ hour} \ x \ \frac{60 \text{ s}}{1\ minute}$$

$$= 2.592 \times 10^6 \text{ s}$$

$$I_2 = \frac{9.075 \times 10^6\ m^3}{2.592 \times 10^6 \text{ s}}$$

$$= 3.5\ m^3/s$$

$$\sum \text{volume inflow} = \frac{I_1 + I_2}{2}$$

$$= \frac{6 + 3.5}{2}$$

$$= 4.75\ m^3/s$$

<u>Answer for Question b</u>

$$\sum \text{volume outflow} = \frac{O_1 + O_2}{2}$$

Information need:
$O_1 = 6.5\ m^3/s$
Le = 70mm = O_2

To use this equation, both O_1 and O_2 must have the same unit. Thus, you have to change one of the units.
Let Le = 70mm change to m^3/s.

- **Step 1: Change mm $\longrightarrow$ m**

$$L_e = 70 \text{ mm} \times \frac{1\ m}{1000\ mm}$$

$$= 0.07 \text{ m}$$

- **Step 2: Derive m $\longrightarrow$ m³**

Repeat the process as step 2 in question a.

$$Le = 0.07 \text{ m} \times 55 \times 10^6 \text{ m}^2$$

$$= 3.85 \times 10^6 \text{m}^3$$

- Step 3: Derive $m^3 \longrightarrow m^3/s$

Repeat the process as step 3 in question a.

$$L_e = \frac{3.85 \times 10^6\ m^3}{2.592 \times 10^6\ s}$$

$$= 1.49 \text{ m}^3/\text{s}$$

$$\sum \text{volume outflow} = \frac{O_1 + O_2}{2}$$

$$= \frac{6.5 + 1.49}{2}$$

$$= 4.0 \text{ m}^3/\text{s}$$

ACTIVITY 5

Watch online for Face-To-Face instruction

Answer for Question c

$$\sum \text{volume inflow} - \sum \text{volume outflow} = \sum \text{change in volume of the system}$$

$$= 4.75 - 4.0 = 0.75 \text{ m}^3/\text{s}$$

Change in storage at the end of month, $\Delta S = \frac{\Delta S}{\Delta t} \times \Delta t$

$$= 0.75 \times 2.592 \times 10^6$$

$$= 1.944 \times 10^6 \text{ m}^3$$

TUTORIAL

1. In the next two months, Johor Bharu District has received rainfall of 300 mm. Evaporation is estimated at 90 mm and infiltration into the subsurface by 25 mm. Calculate the volume of runoff to be stored in the reservoir if the catchment area is 80 km^2.

Answer : $V_r = 14.8 \times 10^6\ m^3$

2. The average annual rainfall of Danau Toba is 2.5 m and the mean annual run-off is 25 m^3/s. If the area of the lake is 35 km^2 , calculate the evaporation of lake. Assume there is no change of storage in the lake.

Answer : $L_e = 0.43m$

3. The lake capacity storage in the beginning of September 2021 is 20 x 10^6 m^3. During this time, the recorded inflow and outflow of the lake is 10 m^3/s and 15 m^3/s respectively. At the end of the month, the lake received a rainfall of 80 cm and the evaporation from the lake was estimated to be 35 cm. The average surface area of the lake was 25 km^2 Calculate the changes of storage and its new storage of the lake (in m^3) at the end of September 2021. Assuming there is no contribution to or from the groundwater storage. (Assume 1 month = 30 days)

Answer : $\Delta S = -855360m^3$, $S_2 = 19.14 \times 10^6$

4. A retention pond has a water elevation of 105.5 m above datum in early January 2020. In that month, the retention pond received an average inflow of 10.0 m^3/s from surface runoff sources. In the same period the outflow from the retention pond had an average value of 4.8 m^3/s. In the same month, the pond received a rainfall of 210 mm and the evaporation from the lake surface was estimated to be 6.10 cm. Calculate the water surface elevation of the pond at the end of the month. The average surface area can be taken as 6500 hectares.

Answer : $H_2 = 103.1m$

STUDENT AND EDUCATOR FEEDBACK

Completing this publication has been a significant challenge for the authors, who have dedicated considerable effort to making the book interactive, informative, and beneficial for both students and educators.

We would greatly appreciate it if you could take a few moments to provide your feedback.

Your input would be a valuable acknowledgment of their hard work.

Thank you for your time and support.

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02

RAINFALL RUNOFF ESTIMATION

Author: SITI NUR FARHANA BINTI ABDUL AZIZ

RAINFALL CHARACTERISTICS

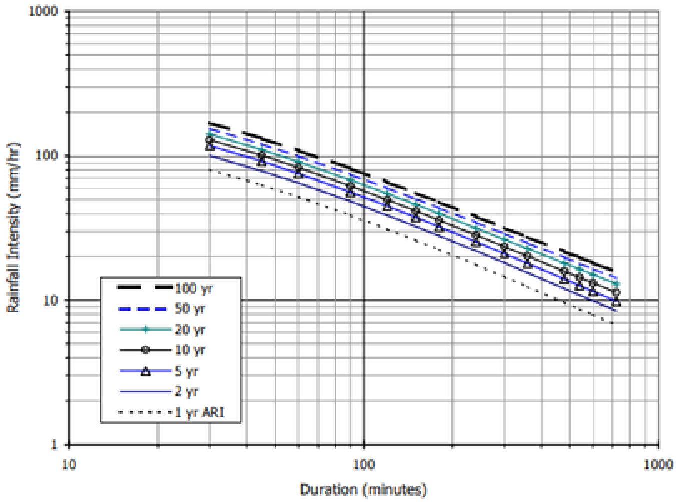
1. DEPTH
2. DURATION
3. AREA
4. FREQUENCY
5. INTENSITY
6. RETURN INTERVAL

INTESITY-DURATION-FREQUENCY CURVE

An intensity-duration-frequency curve (IDF curve) is a mathematical function that relates the intensity of an event (e.g. rainfall) with its duration and frequency of occurrence. These curves are commonly used in hydrology for flood forecasting and civil engineering for urban drainage design.

> The total storm rainfall depth at a point, for a given rainfall duration and ARI, is the function of local climate. Rainfall depth can be further processed and converted into rainfall intensities (intensity = depth/duration) which are then presented in IDF curves.
>
> ***Department of Irrigation and Drainage (DID), Malaysia***

As an input in storm water design processes, Local authorities are advised to find out from the DID to the availabilities of IDF curves for the respective area, or to obtain local pluviometer data for those wishing to conduct their own analysis.



IDF Curves for Kuala Lumpur

Figure above shows IDF Curves for Kuala Lumpur plotted using fitted coefficients obtain from equation 7.

$$\ln(I)=a+b\ln(t)+c(\ln(t))^2+d(\ln(t))^3 \quad (7)$$

AVERAGE RAINFALL DATA

A single point precipitation measurement is quite often not representative of the volume of precipitation falling over a given catchment area. A dense network of point measurements and/or radar estimates can provide a better representation of the true volume over a given area.

Normal or average rainfall is the amount of precipitation that we expect per year (in a given area). It is obtained and set by calculating the average or mean of precipitation recorded in an area during a year.

A network of precipitation measurements can be converted to areal estimates using any of a number of techniques or methods.

Average rainfall data can be calculate using these methods:

1. ARITHMETHIC AVERAGE METHOD
2. POLYGON THIESSEN METHOD
3. ISOHYETAL METHOD

ARITHMETHIC AVERAGE METHOD

Simplest method to calculate mean rainfall data over a basin.
The result is obtained by dividing the sum of rain depths recorded at different rain gauge stations of the basin by the number of the stations.

If the rain gauges are uniformly distributed over the area and the rainfall varies in a very regular manner, the results obtained by this method is acceptable and will not have much different with those calculated using other methods. This method can be used for the storm rainfall, monthly or annual rainfall average computations.

Arithmetic average value can be calculate using the following equation:

$$\bar{P} = \frac{P_1 + P_2 + P_3 + \dots\dots\dots\dots + P_n}{n} \quad \text{(8)}$$

Where,

$\bar{P}$ = *average precipitation over the catchment area* (*for a given time period*)

$P_1, P_2, P_3, \dots\dots\dots\dots, P_n$ *are the precipitations in a given time period at stations* $1, 2, 3, \dots\dots, n$ *respectively within the catchment*

Equation 8 can also be simplified to:

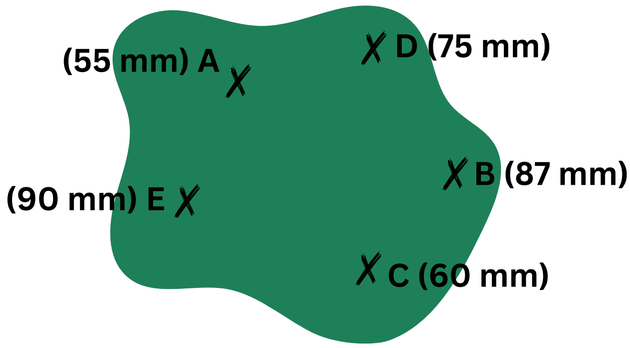
$$\frac{1}{n}\sum_{1}^{n} P_i \quad \text{(9)}$$

ACTIVITY 6

Let's find out how to measure rainfall data

EXAMPLE 2.1

Based on the figure given, calculate the areal rainfall data using arithmetic average method.



Solution

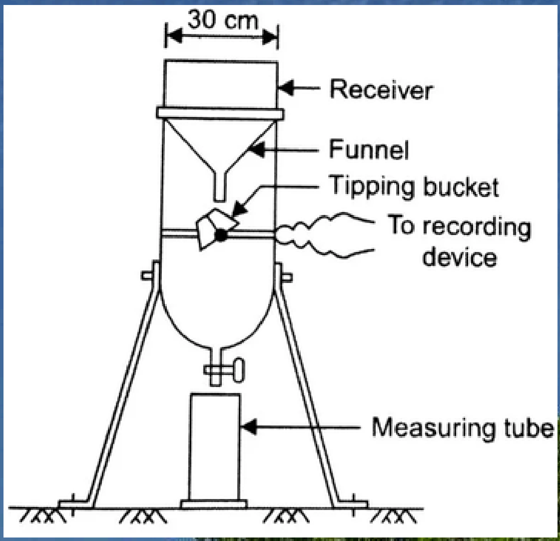
By using equation 8,

$$\bar{P} = \frac{P_1 + P_2 + P_3 + \dots\dots\dots\dots + P_n}{n} \quad (8)$$

$$\bar{P} = \frac{55 + 75 + 87 + 60 + 90}{5}$$

$$\underline{\bar{P} = 73.4 \text{ mm}}$$

SOURCE : DEPARTMENT OF IRRIGATION AND DRAINAGE NEGERI KEDAH



QUICK FACT

Telemetric Station from DID is able to provide real time rainfall and water level on-line enable close monitoring of the development of floods at critical flood prone areas and drought situation in the river basin. This will then allow for the proper, timely and smooth co-ordination of essential disaster relief operations and management to the affected areas.

POLYGON THIESSEN METHOD

In this method, all the neighbouring stations are connected to each other to form a series of triangles. Then the perpendicular bisectors of the triangle sides are drawn. For each station, the bisectors surrounding it will form a polygon.

The precipitation in the polygon region can then be represented by the precipitation measured at that station, which is also the only station within the polygon. This Polygon is named Thiessen polygon.

The Thiessen polygon method assumes that each precipitation gage does not have the same weight as in the arithmetic method. Rainfall recorded at each station is given a weightage based on the area closest to the station

This method is more suitable under the following conditions:

- For areas of moderate size.
- When rainfall stations are few compared to the size of the basin.
- In moderate rugged areas.

Polygon Thiessen value can be calculate using the following equation:

$$P_{avg} = \sum_{i=1}^{m} w_i P_i \qquad (10)$$

where,

$$\sum_{i=1}^{m} w_i = 1.$$

In the Theissen polygon method,

$$w_i = \frac{A_i}{A_T};$$

where,

A_T = Total basin or watershed area.
A_i = Area defined by the Theissen polygons.

The equation can also be write as:

$$\bar{P} = \frac{A_1}{A_T}P_1 + \frac{A_2}{A_T}P_2 + \frac{A_3}{A_T}P_3 + \dots\dots\dots + \frac{A_n}{A_T}P_n \quad (11)$$

DID YOU KNOW?

HOW TO MEASURE RAIN??

- A rain gauge is an instrument used by meteorologists and hydrologists to gather and measure the amount of liquid precipitation over a predefined area, over a period of time.
- It is used to determine the depth of precipitation (usually in mm) that occurs over a unit area and measure rainfall amount.
- Rain gauge also known as udometer, pluviometer, ombrometer, and hyetometer

EXAMPLE 2.2

Based on the following data, calculate areal value using Polygon Theissen method.

STATION	PRECIPITATION, P (mm)	AREA, A (m^2)
A	16.5	18
B	37.1	311
C	48.8	282
D	68.3	311
E	39.1	52

Solution

By using equation 11,

$$\bar{P} = \frac{A_1}{A_T}P_1 + \frac{A_2}{A_T}P_2 + \frac{A_3}{A_T}P_3 + \ldots\ldots\ldots + \frac{A_n}{A_T}P_n \quad (11)$$

A_T = 18 + 311 + 282 + 311 +52

= 974

$$\bar{P} = \frac{18}{974}16.5 + \frac{311}{974}37.1 + \frac{282}{974}48.8 + \frac{311}{974}68.3 + \frac{52}{974}39.1$$

$\bar{P}$ = 50.18 mm

This question can also be solve using the following method:

STATION	PRECIPITATION, P (mm)	AREA, A (m^2)	$W = A_i / A_T$	P X W (mm)
A	16.5	18	**18/974 =0.018**	**16.5 x 0.018 =0.3**
B	37.1	311	**0.319**	**11.8**
C	48.8	282	**0.290**	**14.2**
D	68.3	311	**0.319**	**21.8**
E	39.1	52	**0.053**	**2.07**
TOTAL		A_T = 974	W_T = 1	**PW = 50.17**

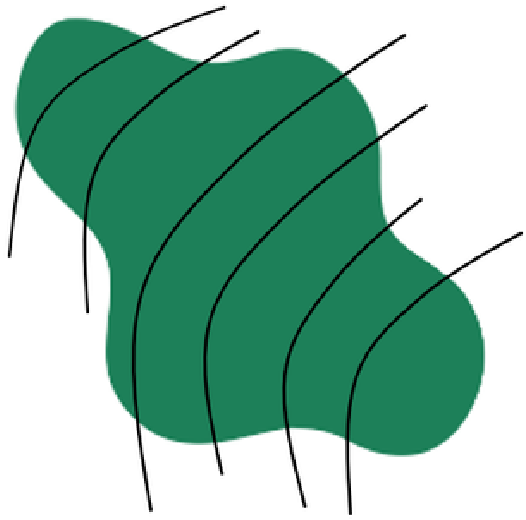
The answer for the question is 50.17 mm

Even tough answer for earliest method is 50.18 mm, the answer for this method is also acceptable.

ISOHYETAL METHOD

Isohyetal method is used to estimate the average precipitation across an area by drawing lines of equal precipitation. In this method, rainfall observations for the considered period are plotted on the map and contours of equal precipitation depth (isohyets) are drawn.

The areal rainfall is determined by the average precipitation between isohyets, multiplied by its area Ai and then dividing the sum of these products by the total area, A.



This method is more suited under the following conditions:

- For hilly and rugged areas.
- For large areas over 5000 km2.
- For areas where the network of rainfall stations within the storm area is sufficiently dense, isohyetal method gives more accurate distribution of rainfall.

ISOHYETAL METHOD

Isohyetal Method value can be calculate using the following equation:

$$\overline{P} = \frac{A_1\left(\frac{P_1+P_2}{2}\right) + A_2\left(\frac{P_2+P_3}{2}\right) + \dots\dots\dots + A_{n-1}\left(\frac{P_{n-1}+P_n}{2}\right)}{A_1 + A_2 + \dots\dots\dots A_n} \qquad (12)$$

where,

$\overline{P}$ = average precipitation over the catchment area (for a given time period)

P_1 , P_2 , P_n = value of isohyetal lines 1,2, n respectively

A_i = Area between pair of isohyet lines

ISOHYETAL METHOD : PROBLEM SOLVING

EXAMPLE 2.3

Calculate the mean areal precipitation for the following data using the Isohyetal Method based on data in table below:

ISOHYETAL LINE	AREA BETWEEN ISOHYETAL LINE (km^2)
1 - 3	85
3 - 6	175
6 - 9	120
9 - 12	128
12 - 15	92

Solution

By using equation 12,

$$\overline{P} = \frac{A_1\left(\frac{P_1+P_2}{2}\right) + A_2\left(\frac{P_2+P_3}{2}\right) + \dots\dots + A_{n-1}\left(\frac{P_{n-1}+P_n}{2}\right)}{A_1 + A_2 + \dots\dots A_n} \quad (12)$$

$$\overline{P} = \frac{85\left(\frac{1+3}{2}\right) + 175\left(\frac{3+6}{2}\right) + 120\left(\frac{6+9}{2}\right) + 128\left(\frac{9+12}{2}\right) + 92\left(\frac{12+15}{2}\right)}{85+175+120+128+92}$$

$$\overline{P} = \frac{170+787.5+900+1344+1242}{600}$$

$$\overline{P} = \mathbf{7.406\ mm}$$

This question can also be solve using the following method:

ISOHYETAL LINE	AREA BETWEEN ISOHYETAL LINE (km^2)	MEAN ISOHYETAL LINE	W = A_i / A_t	P X W (mm)
1 - 3	85	2	**85/600 =0.142**	**2 x 0.14=0.283**
3 - 6	175	4.5	**0.292**	**1.313**
6 - 9	120	7.5	**0.200**	**1.500**
9 - 12	128	10.5	**0.213**	**2.240**
12 - 15	92	13.5	**0.153**	**2.070**
TOTAL	**A_t = 600**		**W = 0.99** *Answer is acceptable*	**PW = 7.406**

TUTORIAL

1 Calculate the mean areal precipitation for the following data using Polygon Thiessen Method.

Answer : P = 35.07mm

Station No.	Precipitation (mm)	Area of Polygon Thiessen (km^2)
1	35	18
2	32	20
3	28	24
4	46	17

2 Estimate the mean precipitation for the data as shown in table below by using the following method:

- Arithmetic average method
- Polygon Thiessen Method.

Answer : Arithmetic P = 88.2mm , Polygon P = 91.04mm

Station *Stesen*	Area (km^2) *Luas (km^2)*	Precipitation (mm) *Curahan (mm)*
1	65	88
2	28	67
3	54	76
4	64	115
5	38	95

3 Recorded precipitation at four rain gauge station in a catchment area are shown in table below. Calculate average rainfall data for all station.

Answer : P =114.6mm

STATION	RAINFALL (mm)	AREA (m^2)
1	85.0	2141
2	135.2	1609
3	95.3	1564
4	146.4	1963

TUTORIAL

4 For a drainage basin of 600km², isohyetals drawn for a storm gave the following data. Calculate the average depth of precipitation.

Answer : P = 8.02mm

ISOHYETAL LINE (mm)	AREA, A (km²)
15 - 20	92
12 - 9	128
9 - 6	120
6 - 3	175
3 - 1	85

5 Based on the following data, calculate areal rainfall value using isohyetal method

Answer : P =35.75mm

ISOHYETAL LINE (mm)	AREA, A (km²)
20 - 30	86
30 - 40	142
40 - 50	97
50 - 60	55
20 - 30	86

MISSING RAINFALL DATA

Some precipitation stations may have short breaks in the records because of absence of the observer or because of instrumental failures. It is often necessary to estimate this missing record. The missing precipitation of a station is estimated from the observations of precipitation at some other stations as close to and as evenly spaced around the station with the missing record as possible.

The station whose data is missing is called interpolation station and gauging stations whose data are used to calculate the missing station data are called index stations.

FACTORS OF MISSING DATA OCCURANCE

1. ABSENCE OF OBSERVER
2. INSTRUMENT FAILURE
3. RELOCATION OF STATION

METHOD FOR MISSING DATA ESTIMATION

Missing rainfall data can be estimate using these methods:

1. NORMAL RATIO METHOD
2. QUADRANT METHOD

NORMAL RATIO METHOD

Normal ratio method can be calculate using the following equation:

$$P_x = \frac{1}{n}\sum_{i=1}^{i=n}\frac{N_x}{N_i}P_i \qquad (13)$$

where,

P_χ = missing rainfall data
N_χ = Normal annual for missing rainfall station
N_i = Normal annual for i-th station
n = Number of total station (exclude missing rainfall station)
P_i = rainfall data for i-th station

Equation 13 can also be written as;

$$P_X = \frac{N_x}{n}\left\{\frac{P_A}{N_A} + \frac{P_B}{N_B} + \frac{P_C}{N_C}\right\} \quad (14)$$

where,

P_χ = missing rainfall data
N_χ = Normal annual for missing rainfall station
$N_{A, B, C}$ = Normal annual for index stations A, B and C
n = Number of total station (NOT include missing rainfall station)
$P_{A, B, C}$ = Rainfall data for index stations A, B and C

NORMAL RATIO METHOD : PROBLEM SOLVING

EXAMPLE 2.4

One of four gauge in a station is broken. Reading from the three functional rain gauges are 20, 26 and 37mm. If normal distribution of rainfall are 520, 560 and 735mm respectively whereas for the broken rain gauge station is 620mm. Calculate reading from the missing station data.

Solution

To help you answer this question, it is advisable to tabulate the given data first.

STATION	RAINFALL (mm)	Normal distribution Rainfall (mm)
1	X	620
2	20	520
3	26	560
4	37	735

By using equation 13,

$$P_r = \frac{1}{n}\sum_{i=1}^{i=n}\frac{N_r}{N_i}P_i \qquad (13)$$

$$P_x = \frac{1}{3}\left(\frac{620}{520}20 + \frac{620}{560}26 + \frac{620}{735}37\right)$$

$$P_x = \frac{1}{3}(23.85 + 28.78 + 31.21)$$

$$P_x = \frac{1}{3}(83.84)$$

P_χ = **27.95 mm**

The rainfall at a station is estimated as a weighted average of the observed rainfall at the neighbouring stations. The weights are equal to the reciprocal of the distance or some power of the reciprocal of the distance of the estimator stations from the estimated stations.

In this method four quadrant are delineated by north-south and east-west line passing. Through the rain gauge station where the missing rainfall is to be estimated.

Let D_i be the distance of the estimator station from the estimated station.

According to the quadrant method, if the weights are an inverse square of distance, the missing precipitation 'Px' is given as:

$$P_X = \frac{\sum_{i=1}^{n} \frac{P_i}{D_i^2}}{\sum_{i=1}^{n} \frac{1}{D_i^2}} \tag{15}$$

where,

P_χ = missing rainfall data
D_i^2 = Distance of the estimator station from the estimated station
P_i = rainfall data for i-th station

The equation can simply be written as;

$$P_X = \frac{\sum W P_i}{\sum W} \quad (16)$$

where,

$$W = 1/\, D^2 \quad (17)$$

Distance, D^2 can be obtain using the following equation;

$$D^2 = x^2 + y^2 \quad (18)$$

*** This equation can only be used if one of the station located at the origin.*

QUADRANT METHOD : PROCEDURE

Basic procedure to use quadrant method:

- Plot the location of all stations
- Build x-y axis through the gauge which missing data as the origin
- Select the four rain gauge stations from each quadrant and the closest to the origin
- Calculate the distance from each station of origin
- Position of station X and index station A, B, C and D

EXAMPLE 2.5

Stations A, B, C, D, E, F is the observation station rainfall data. Record for station A is not complete because of flooding. Rainfall values for the other stations are 40, 45, 37.5, 50 and 42.5mm. The quadrant of the four have been drawn, the coordinates for the station is B (4,2), C (-1,-6), D (3, -2), E (-3,3) and F (-2,-2). Calculate the amount of rainfall for station A.

Solution

To help you answer this question, it is advisable to tabulate the given data first.

STATION	RAINFALL (mm)	COORDINATE	
		x-axis	y-axis
A	X	**0**	**0**
B	40	**4**	**2**
C	45	**-1**	**-6**
D	37.5	**3**	**-2**
E	50	**-3**	**3**
F	42.5	**-2**	**-2**

To obtain missing data using quadrant method, first, you have to identify 1 station to represent each quadrant.

Identify quadrant from each estimator station first.

STATION	RAINFALL (mm)	COORDINATE		QUADRANT
		x-axis	y-axis	
A	X	**0**	**0**	**-**
B	40	**4**	**2**	**I**
C	45	**-1**	**-6**	**III**
D	37.5	**3**	**-2**	**IV**
E	50	**-3**	**3**	**II**
F	42.5	**-2**	**-2**	**III**

From the identification, quadrant III have shown more than 1 estimator stations in the quadrant.

Calculate the distance, D_i^2 of each estimator station from estimated station. The smallest distance will be choose to represent each quadrant.

By using equation 18, and information of Station B as an example, distance from Station B to Station A can be calculated using equation 18.

$$D^2 = x^2 + y^2 \quad (18)$$

From the equation,

Station B
Coordinate x - axis : 4
Coordinate y - axis : 2

Distance of station B to Station A (0,0)

$$D^2 = x^2 + y^2$$
$$= 4^2 + 2^2$$
$$= 20$$

Calculate distance from each estimator station to estimated station respectively and tabulate the distance in the table as follow.

STATION	RAINFALL (mm)	COORDINATE		QUADRANT	DISTANCE
		x-axis	y-axis		
A	X	0	0	-	-
B	40	4	2	I	20
C	45	-1	-6	III	37
D	37.5	3	-2	IV	13
E	50	-3	3	II	18
F	42.5	-2	-2	III	8

From the table, you could see that Station C and F were located in the same quadrant. The shortest distance of those station to Station A will be choose. In this case, Station F have the shortest distance, thus represent quadrant III.

So you can neglect data from Station C.

By using equation 17, calculate weightage, W for each estimator station.

$$W = 1/D^2 \quad (17)$$

For example;

Use information for Station B. $D^2 = 20$

$$W = 1/D^2$$
$$= 1/20$$
$$= 0.05$$

STATION	RAINFALL (mm)	COORDINATE		QUADRANT	DISTANCE	$w = 1/D^2$
		x-axis	y-axis			
A	X	0	0	-	-	-
B	40	4	2	I	20	0.050
C	45	-1	-6	III	37	x
D	37.5	3	-2	IV	13	0.077
E	50	-3	3	II	18	0.056
F	42.5	-2	-2	III	8	0.125

To use equation 16, you must have data for PW which is rainfall data multiple by weightage.

For example;

Use information for Station B. P = 40, W = 20

$$PW = 40 \times 20$$
$$= 800$$

STATION	RAINFALL (mm)	COORDINATE		QUADRANT	DISTANCE D^2	$w = 1/D^2$	PW
		x-axis	y-axis				
A	X	0	0	-	-	-	-
B	40	4	2	I	20	0.050	2
C	45	-1	-6	III	37	x	x
D	37.5	3	-2	IV	13	0.077	2.888
E	50	-3	3	II	18	0.056	2.8
F	42.5	-2	-2	III	8	0.125	5.313
TOTAL						0.335	14.216

$$P_X = \frac{\sum WP_i}{\sum W} \qquad (16)$$

By using this equation, you can finally calculate missing rainfall data for Station A.

$$P_A = \frac{14.216}{0.335}$$

$$P_a = 42.436 \text{ mm}$$

TUTORIAL

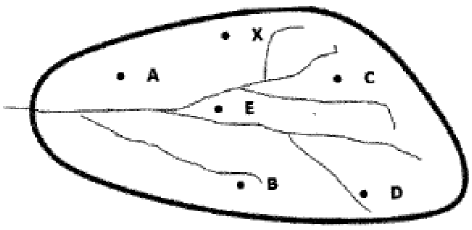
1 According to the table below, calculate missing rainfall data by using Normal Ratio Method.

Answer : Px = 68.11mm

Precipitation / *curahan*(mm)	66	79	58	X
Annual Rainfall / *hujan tahunan* (mm)	1067	1041	991	1041

2 One of four rain gauges in a station is broken. Reading from three functional rain gauges are 20, 26 and 37 mm. If normal distribution of rainfall are 520, 560 and 735 mm respectively whereas for the broken gauge is 620 mm, calculate reading from the missing data station.

Answer : Px = 28mm



3 The above figure shows a distribution of rain gauge station in a catchment. Determine the missing amount of rainfall for gauge X using normal ratio method.

Answer : Px = 11.9mm

Station, ***Stesen***	**Monthly precipitation,** ***Hujan bulanan(mm)***	**Annual precipitation,** ***Hujan tahunan(mm)***
X	?	110.5
A	10.3	96.3
B	9.5	110.3
C	13.0	93.0
D	11.6	106.3
E	9.6	100.6

TUTORIAL

4 Station X failed to report the rainfall recorded during a storm. With respect to east-west and north-south axes set up at station X, the coordinated of 4 surrounding gauges, which are the nearest to the station X respective quadrants, are (10,15), (-8 ,5), (-12, -9), and (5,-15) km respectively. Determine the missing rainfall at X, if the storm rainfalls at the four surrounding are 73, 89, 68 and 57mm respectively.

Answer : Px = 77mm

5 Calculate the missing rainfall data for station K in the month of July 24, when the rainfall data for other three stations J, P and N are available as follow:

Answer : Px = 100.55mm

STATION	PRECIPITATION (mm)	COORDINATE
X	-	**4, 5**
A	100	**5,6**
B	109	**-1,7**
C	115	**5,-3**
D	90	**-7,-8**

STUDENT AND EDUCATOR FEEDBACK

Completing this publication has been a significant challenge for the authors, who have dedicated considerable effort to making the book interactive, informative, and beneficial for both students and educators.

We would greatly appreciate it if you could take a few moments to provide your feedback.

Your input would be a valuable acknowledgment of their hard work.

Thank you for your time and support.

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03

RIVER FLOW MEASUREMENT

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RUNOFF RATE AND VOLUME

Runoff means the draining or flowing off of precipitation from a catchment area through a surface channel enters into a stream channel.

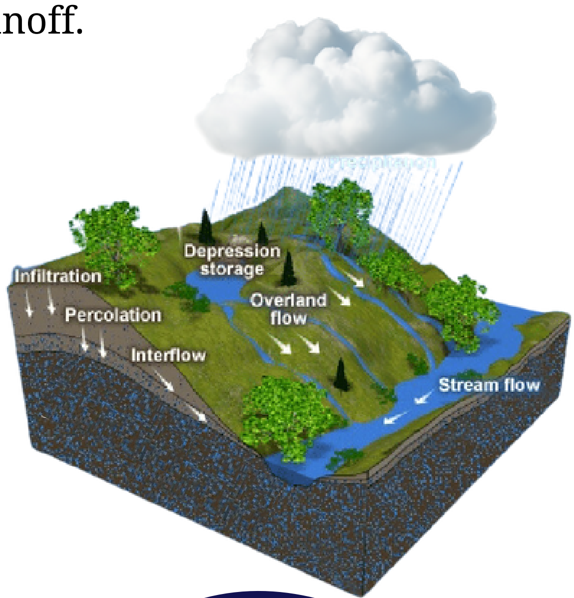
Based on the time delay between the precipitation and the runoff, the runoff is classified into two categories.

1. DIRECT FLOW
2. BASE FLOW

RUNOFF CATEGORY : DIRECT RUNOFF

It is the part of runoff which enters the stream **IMMEDIATELY** after the rainfall. It includes surface runoff, prompt interflow and rainfall on the surface of the stream.

In the case of snow-melt, the resulting flow entering the stream is also a direct runoff. Direct storm runoff and storm runoff are also used to designate direct runoff.

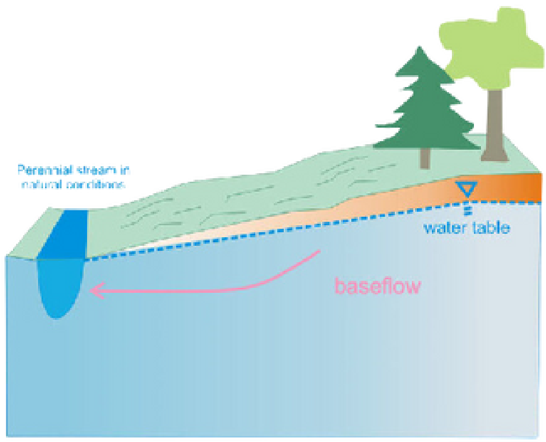


RUNOFF CATEGORY : BASE FLOW

The **DELAYED FLOW** that reaches a stream essentially as groundwater flow is called base flow.

Baseflow is the sustained or "fair-weather" runoff of prior precipitation that was stored temporarily in the watershed, plus the delayed subsurface runoff from the current storm.

Some conceptual models of watershed processes account explicitly for this storage and for the subsurface movement.



FACTORS AFFECTING RUNOFF RATE AND VOLUME

Factors affecting runoff rate and volume can be divide into two categories;

1. PHYSIOGRAPHICAL FACTORS
2. HUMAN FACTORS

1 SIZE OF WATERSHED

Larger watersheds collect more precipitation, leading to higher runoff volumes.

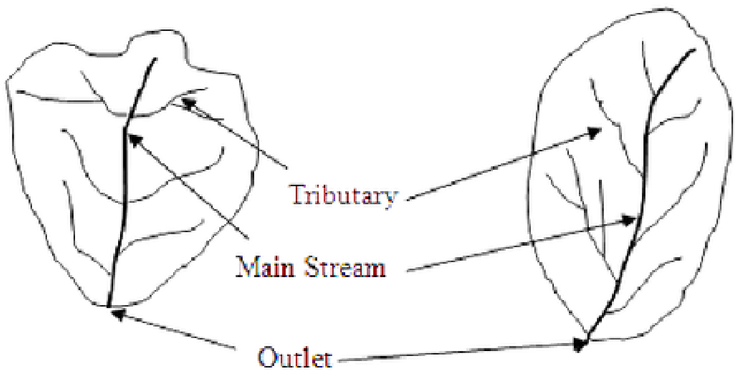
A large watershed takes longer time for draining the runoff to outlet than smaller watershed and vise-versa.

More intense rainfall events are generally distributed over a relatively smaller area, i.e., larger the area lower will be the intensity of rainfall.

2 SHAPED OF WATERSHED

Long, narrow watersheds have slower runoff rates than round, compact ones.

Fan shaped catchments give greater runoff because tributaries are nearly of same size and hence time of concentration of runoff is nearly same. On the contrary, discharges over fern leaf arrangement of tributaries are distributed over long period because of the different lengths of tributaries.



Fan shaped catchment Leaf shaped catchment

3 TOPOGRAPHIC CHARACTERISTICS

The runoff depends upon surface condition, slope and land features. Runoff will be more from a smooth surface than from rugged surface.

Steeper slopes lead to faster runoff, while flat areas promote infiltration and slower runoff.

4 ORIENTATION OF WATERSHED

The direction of a watershed can affect runoff due to sunlight exposure, wind patterns, and precipitation distribution.

This affects the evaporation and transpiration losses from the area. The north or south orientation, affects the time of melting of collected snow.

5 LAND USE

The direction of a watershed can affect runoff due to sunlight exposure, wind patterns, and precipitation distribution. This affects the evaporation and transpiration losses from the area.

The north or south orientation, affects the time of melting of collected snow.

6 SOIL MOISTURE

Magnitude of runoff yield depends upon the initial moisture present in soil at the time of rainfall. Soil saturated with water cannot absorb more, leading to higher runoff.

7 SOIL TYPE

Different soils have varying infiltration capacities. In general, when the rate of infiltration and transmission through the soil is higher, the volume of runoff is lower. As a result of low infiltration and transmission rates, fine textured soils, such as clay, produce a higher runoff volume than do coarse textured soils, such as sand.

Sites having clay soils may require the construction of more elaborate drainage systems than sites having sandy soils.

8 DRAINAGE DENSITY

It is defined as the ratio of the total channel length [L] in the watershed to total watershed area [A].

Higher drainage density means water is collected and transported quickly, increasing runoff rates.

9 CHANNEL LENGTH

The length of a watershed is the distance between the headwaters and the discharge point. This mainly impacts how long it takes for runoff to reach the discharge point.

Hence, the longer the watershed, the longer it would take for runoff to be discharged.

PHYSIOGRAPHICAL FACTORS

10 STORAGE

The artificial storage such as dams, weirs etc. and natural storage such as lakes, ponds etc. tend to reduce the peak flow. They also give rise to greater evaporation losses.

Natural and artificial storage areas temporarily hold water, reducing and delaying runoff.

HUMAN FACTORS

1 DRAINAGE SYSTEM

Efficient drainage systems reduce flooding risk and increase runoff volume and rate by reducing infiltration.

2 URBANIZATION

Urbanization transforms natural landscapes into built environments, increasing runoff volumes and rates. Urban development can greatly increase the amount of precipitation that is converted to runoff in a drainage basin. Most paved surfaces and rooftops allow no water to infiltrate, but instead divert water directly to storm channels and drains.

Streamflow is of fundamental importance of virtually all environmental monitoring and effects almost all other environmental issues connected with water. The flow of rivers changes significantly in a very short amount of time due to plenty of factors.

Streamflow measurement can yield information on changes in discharge that are valuable for predicting flooding, estimating long-terms trends in water and sediment discharge, and for distinguishing possible long term climate change.

Stream discharge can be measured using the following method:

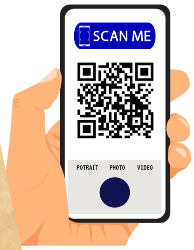
1 FLOAT GAUGING

Involves measuring the velocity of a neutral buoyancy object (e.g., foam golf ball or float) multiplying this by the average cross-sectional area of the river
Prosedure: Select a straight section of the river with uniform flow. Mark Distance. Release the Float. Time the Float. Calculate Velocity.

2 CURRENT METERING

The most common approach to determining discharge is the so called conventional current-meter method. The method is based on determining the mean streamflow velocity and flow cross sectional area; the product of these variables determines the stream discharge.

Current Meter



ACTIVITY 7

Let's find out how to use current meter

3 RADAR GUN METHOD

Procedure : Select a measurement point where the river is accessible and flow conditions are suitable. Aim the Radar Gun at the surface of the water. Measure Surface Velocity. Calculate Average Velocity.

4 ACOUSTIC DOPPLER CURRENT PROFILER

Deploy the ADCP on a boat or stationary platform. Measure Doppler Shifts. Profile the Velocity. Process the Data.

5 SLOPE-AREA METHOD

When it is not possible to make direct measurement especially during floods, slope-area method is a most commonly used indirect method of measurement.

In this method, discharge is computed on the basis of a uniform flow equation involving channel characteristics, water surface profile and a roughness coefficient. The drop in water surface profile for a uniform reach of channel represents losses caused by bed roughness.

QUICK FACT

The salt dilution method also can be used to measure rive flow. It involves injecting (inserting) a known amount of salt into a stream. This process is technically known as slug injection. The salt acts as a tracer to measure the discharge. The concentration of dissolved salt is measured downstream at a point where it has fully mixed with the stream water.

The hydrographer measures stream depth and velocity at selected intervals across a stream's cross section. The hydrographer may be wading, or supported by a cableway, bridge, ice cover, or a boat.

Three method involved in calculating streamflow measurement are:

1. VELOCITY AREA METHOD
2. MID SECTION METHOD
3. MEAN SECTION METHOD

VELOCITY AREA METHOD

The most practical method of measuring stream discharge is through the velocity-area method. Discharge is determined as the product of the cross-sectional area of the water multiply to velocity. Measuring the average velocity of an entire cross section is impractical, so mid-section velocity-area method was used.

Using this method, the width of the stream is divided into a number of increments, each usually containing no more than 5% of the total discharge. For each incremental width, stream depth and average velocity are measured.

VELOCITY AREA METHOD

The velocity averaged over the vertical at each section is known. The total discharge is then calculate using the following equation:

$$Q = \sum(v_i \times A_i) \tag{19}$$

where,

Q = Total discharge (m^3/s)
V_i = Velocity of segment i (m/s)
A_i = Cross-sectional area of segment (m^2)

VELOCITY AREA METHOD : PROBLEM SOLVING

EXAMPLE 3.1

Based on the data taken at Sungai Aru, calculate the discharge in the stream using Velocity-Area Method. Given the rating equation of the current meter is V = 0.15N + 0.03 m/s.

DISTANCE FROM LEFT OF WATER EDGE (m)	0	1.0	3.0	5.0	7.0	9.0	10.0
DEPTH (m)	0	1.5	1.8	2.0	1.6	1.0	0
REVOLUTIONS OF A CURRENT METER KEPT AT 0.6 DEPTH	0	30	57	95	53	28	0
DURATION OF OBSERVATION (s)	0	100	100	150	100	100	0

VELOCITY AREA METHOD : PROBLEM SOLVING

Solution

DISTANCE FROM RIVER BANK (m)	VERTICAL DEPTH (m)	IMMERSION OF CURRENT METER DEPTH	DEPTH OF OBSERVATION	NUMBER OF ROTATION	TIME (s)	NUMBER OF ROTATION PER TIME (rev/s)	VELOCITY AT POINT (m/s)	MEAN VELOCITY IN VERTICAL (m/s)	MEAN VELOCITY IN SECTION (m/s)	WIDTH OF SECTION (m)	MEAN DEPTH (m)	AREA OF SECTION (m²)	DISCHARGE
0	0	0	0	0	0	0	0	0	0				
1	1.5	0.6D	0.9	30	100	0.30	0.08	0.08	0.05	1	0.75	0.75	0.039
3	1.8	0.6D	1.08	57	100	0.57	0.12	0.12	0.10	2	1.65	3.3	0.314
5	2	0.6D	1.2	95	150	0.63	0.13	0.13	0.12	2	1.9	3.8	0.457
7	1.6	0.6D	0.96	53	100	0.53	0.11	0.11	0.12	2	1.8	3.6	0.422
9	1	0.6D	0.6	28	100	0.28	0.07	0.07	0.09	2	1.3	2.6	0.236
10	0	0.6D	0	0	0	0.00	0.00	0.00	0.05	1	0.5	0.5	0.000
Total													1.468

MEAN SECTION METHOD

In this method, discharges are computed for subsections between successive observation verticals. The velocities and depths at successive verticals are each averaged; each subsection extends laterally from one observation vertical to the next.

The subsection discharge is the product of the average of two mean velocities, the average of two depths, and the distance between observation verticals

$$Q = \sum\left(\frac{(d_i + d_{i+1})}{2} \times w_i \times v_i\right) \tag{20}$$

where,

Q = Total discharge (m^3/s)
d_i, d_{i+1} = Depths at consecutive points (m)
w_i = width between points (m)
V_i = velocity at segment i (m/s)

MID SECTION METHOD

In this method, the stream cross section is divided into rectangular subsections. At the center of each of these subsections (called a vertical), a depth and velocity measurement is made, and the distance from a datum point on the shore is determined.

The total discharge can be determined using the equation as follow:

$$Q = \sum\left(\frac{(d_i + d_{i+1})}{2} \times \frac{(w_{i-1} + w_i)}{2} \times v_i\right) \tag{21}$$

EXAMPLE 3.2

A stream cross section has been divided into five subsections. The area of each subsection and its mean velocity are given in table below. Calculate the stream flow of the cross section.

SUBSECTION	I	II	III	IV	V
AREA (m^2)	0	1.5	1.8	2.0	1.6
MEAN VELOCITY (m/s)	0	30	57	95	53

Solution

SUBSECTION	AREA (m^2)	MEAN VELOCITY (m/s)	Discharge Q (m^3/s)
I	0	0	0.50
II	1.5	30	1.08
III	1.8	57	2.50
IV	2.0	95	2.59
V	1.6	53	0.72
Total Q (m^3/s)			7.39

EXAMPLE 3.3

Using data given, estimate the discharge by mean section method and mid method.

DISTANCE (m)	DEPTH (m)	VELOCITY (m/s)
3.0	0.0	0.0
6.0	1.1	0.3
9.0	1.7	0.4
12.0	2.0	0.4
15.0	2.1	0.4
18.0	2.1	0.3
21.0	1.9	0.3
24.0	1.8	0.3
27.0	1.8	0.3
30.0	1.6	0.3
33.0	1.3	0.3
36.0	1.4	0.2
39.0	1.3	0.2
42.0	1.6	0.1
45.0	1.5	0.1
48.0	0.0	0.0

MID SECTION METHOD : PROBLEM SOLVING

Solution

DISTANCE	DEPTH	VELOCITY	MEAN SECTION METHOD				MID SECTION METHOD	
			(Ví-l + Ví)/2	(dí-l + dí)/2	(bí-l - bí)	qí	(bí+l - bí-l)/2	qí
3.0	0.0	0.0	0.17	0.57	3.00	0.28	3.00	0.00
6.0	1.1	0.3	0.34	1.44	3.00	1.48	3.00	1.12
9.0	1.7	0.4	0.36	1.87	3.00	2.00	3.00	1.86
12.0	2.0	0.4	0.36	2.03	3.00	2.16	3.00	2.14
15.0	2.1	0.4	0.35	2.06	3.00	2.14	3.00	2.18
18.0	2.1	0.3	0.34	1.98	3.00	2.04	3.00	2.10
21.0	1.9	0.3	0.34	1.83	3.00	1.88	3.00	1.98
24.0	1.8	0.3	0.33	1.75	3.00	1.72	3.00	1.79
27.0	1.8	0.3	0.32	1.68	3.00	1.60	3.00	1.65
30.0	1.6	0.3	0.32	1.45	3.00	1.39	3.00	1.55
33.0	1.3	0.3	0.28	1.37	3.00	1.16	3.00	1.24
36.0	1.4	0.2	0.21	1.37	3.00	0.88	3.00	1.06
39.0	1.3	0.2	0.14	1.47	3.00	0.63	3.00	0.71
42.0	1.6	0.1	0.09	1.58	3.00	0.40	3.00	0.51
45.0	1.5	0.1	0.03	0.76	3.00	0.07	3.00	0.30
48.0	0.0	0.0	0.00	0.00	-48.00	0.00	-22.50	0.00
			0	0	Σqí =	19.84	Σqí =	20.19

TUTORIAL

1 Based on the data given table below, calculate the average velocity in the stream. Given the rating equation of the current meter is where v is in m/s and N is rev/s

DISTANCE FROM THE LEFT WATER EDGE (m)	DEPTH (m)	NUMBER OF ROTATION PER TIME (rev/s)		
		0.6d	0.2d	0.8d
0	0			
2	1.5	14		
4	2.6		50	44
6	4		75	52
8	7		43	37
10	4.5		38	32
12	3		36	29
14	1.6	12		
15.5	0			

2 Based on current meter gauging data given in table below, compute the stream flow using the following method:

a) Mean section method

b) Mid section method

DISTANCE FROM LEFT BANK, b (m)	DEPTH, d (m)	MEAN VELOCITY, v (m/s)
0	0	0.000
3	1.54	0.330
6	1.81	0.350
9	2.30	0.340
12	3.15	0.356
15	2.00	0.322
18	1.30	0.180
21	0	0.000

3 The following data in Table 3.1 were collected during a stream gauging operation in a river. Compute the discharge

4 Calculate the discharge of river given the following measurement made with a flow meter in Table 3.2

TABLE 3.1

DISTANCE FROM THE LEFT WATER EDGE (m)	DEPTH (m)	VELOCITY, v (m/s)	
		0.2d	0.8d
0.0	0.0	0.0	0.0
1.5	1.3	0.6	0.4
3.0	2.5	0.9	0.6
4.5	1.7	0.7	0.5
6.0	1.0	0.6	0.4
7.5	0.4	0.4	0.3
9.0	0.0	0.0	0.0

TABLE 3.2

DISTANCE FROM THE LEFT WATER EDGE (m)	DEPTH (m)	VELOCITY, v (m/s)	
		0.2d	0.8d
0.0	0.0	0.0	0.0
0.6	0.3	0.42	0.21
1.2	1.29	0.57	0.36
1.8	2.16	0.78	0.54
2.4	2.55	0.87	0.60
3.0	2.22	0.81	0.30
3.6	1.68	0.75	0.51
4.2	1.41	0.69	0.45
4.8	1.05	0.63	0.39
5.4	0.63	0.54	0.33

STUDENT AND EDUCATOR FEEDBACK

Completing this publication has been a significant challenge for the authors, who have dedicated considerable effort to making the book interactive, informative, and beneficial for both students and educators.

We would greatly appreciate it if you could take a few moments to provide your feedback.

Your input would be a valuable acknowledgment of their hard work.

Thank you for your time and support.

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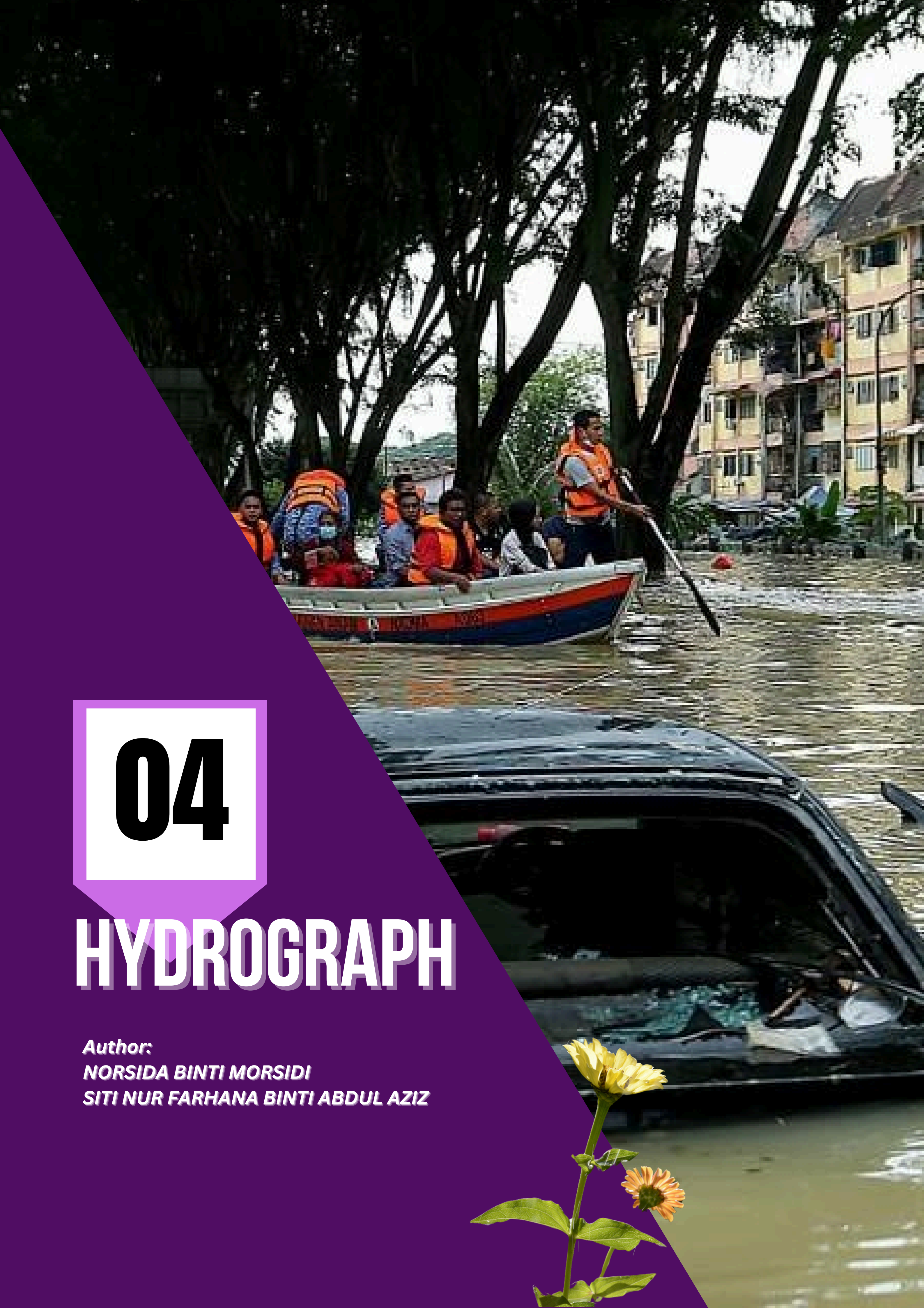

04

HYDROGRAPH

Author:
NORSIDA BINTI MORSIDI
SITI NUR FARHANA BINTI ABDUL AZIZ

A storm hydrograph is a way of displaying how the discharge of a river can change over time in response to a rainfall event.

The discharge of a river is just the amount of water passing a certain point every second, and is calculated by multiplying the cross sectional area of the river by its velocity

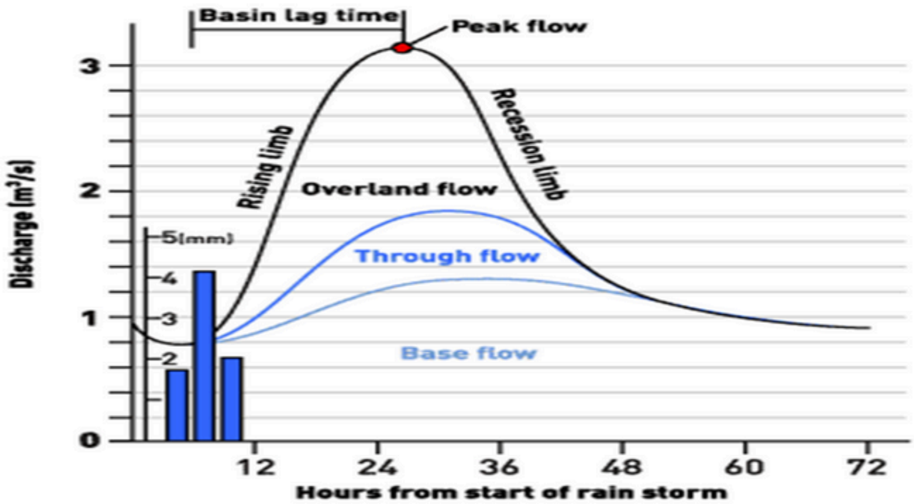

Figure 4.1 The graph showing the rate of low (discharge) over time.

Hydrograph can be categorized into three category:

1 NATURAL HYDROGRAPH

Natural hydrograph is a record and graphical representations of discharge as a function of time at specific location. This hydrograph can be obtained directly from the flow records of a gauged stream.

2 SYNTHETIC HYDROGRAPH

Synthetic Hydrograph can be obtained by using watershed parameters and storm characteristics to simulate a natural hydrograph

3 UNIT HYDROGRAPH

A discharge hydrograph resulting from 1 inch or 1 cm of direct runoff distributed uniformly over the watershed resulting from a rainfall of a specified duration.

NATURAL HYDROGRAPH

Component of natural hydrograph are as follows:

1 RISING LIMB	The normal (base) flow of the river starts to rise when run-off, ground and soil water reaches the river.
2 PEAK DISCHARGE	Maximum discharge in the river, the time when the river reaches its highest flow
3 FALLING LIMB	Shows that water is still reaching the river but in decreasing amounts of runoff
4 BASE FLOW	Base flow is the longer-term discharge into a stream from natural storages such as groundwater flow

5 **DIRECT FLOW**

Water that flows over the ground surface or through the ground directly into streams, rivers and lakes.

6 **BASIN LAG TIME**

The time it takes for the water to find its way to the river

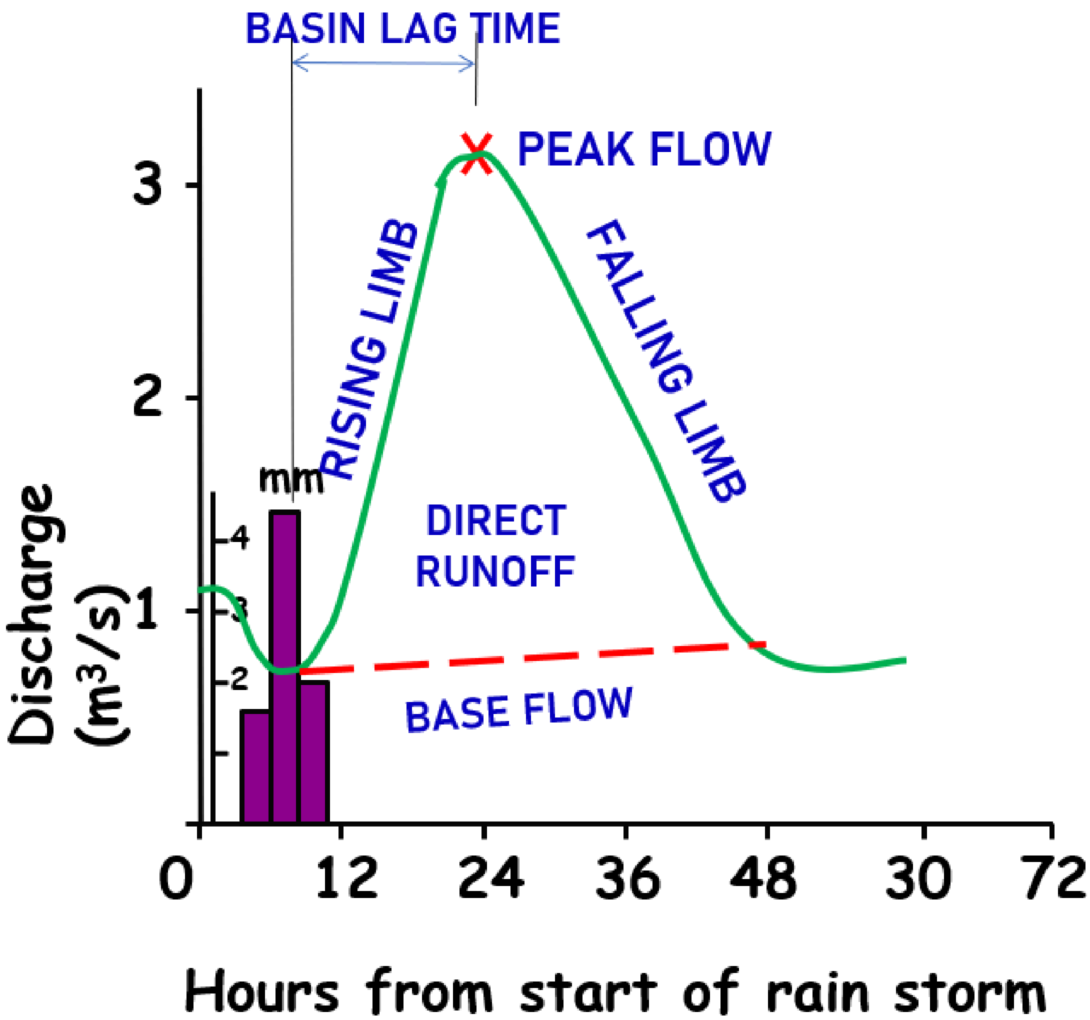

Figure 4.2 Hydrograph an its component

1 STEEPNESS OF SLOPE

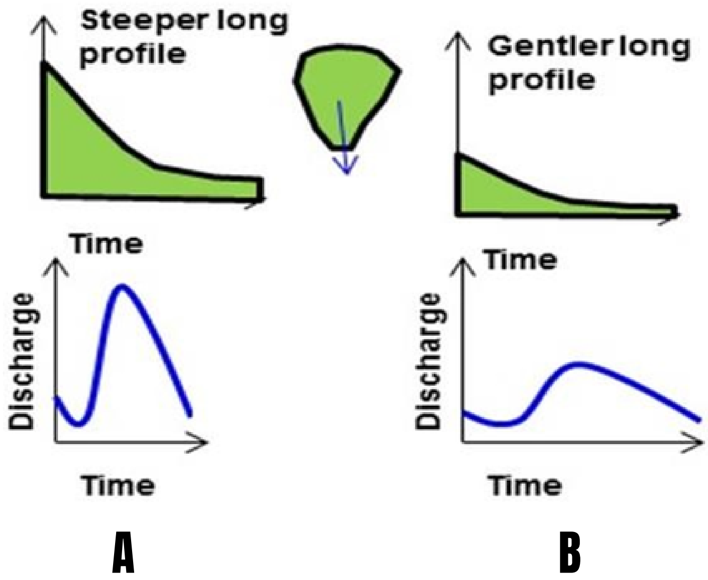

Figure 4.3 Different of hydrograph based on slope steepness

The steeper the basin the more quickly it drains. Gentler basin gives time for water to infiltrate and reduce runoff rate.

Slope A shows a basin with steeper slope thus lead to high peak flow in a short time. Slope B shows a gentler slope and contribute to a low peak flow and longer time needed to achieve peak flow.

2 BASIN SHAPE

A circular shaped drainage basin leads to rapid drainage whereas a long drainage basin will take time for the water to reach the river.

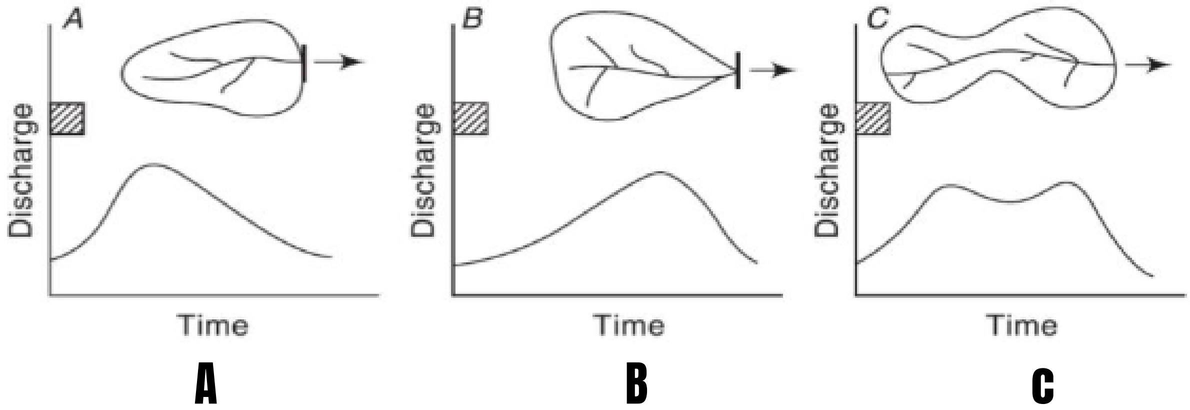

Figure 4.4 Effect of basin shape on hydrograph

ACTIVITY 8

Can you guess which shape gives higher flow rate in a short period?

3 DENSITY DRAINAGE

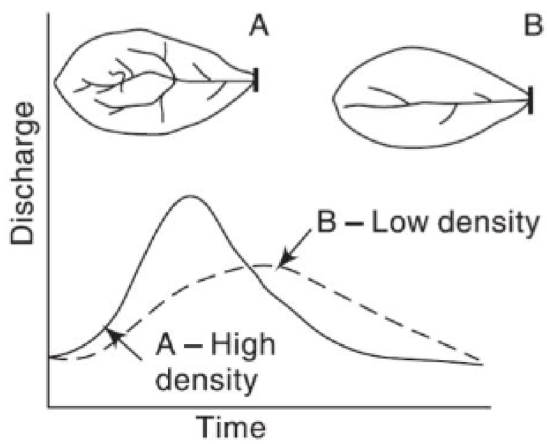

Figure 4.5 Effect of drainage density on hydrograph

Density drainage is a ratio of total drainage length with total drainage area.

A basin with many tributaries will offer high runoff and flow more quickly so the rising limb will be more steeper with a shorter lag time.

4 VEGETATION

Land with vegetation can reduce discharge as it intercepts precipitation. Vegetation can absorb and hinder surface runoff from reaching the river. In addition, densely vegetated areas in tropical regions can intercept rainwater and less water reaches the surface as runoff.

5 SOIL PERMIABILITY

The permeability of the ground surface can impact the lag time. If the ground is permeable, then water can infiltrate through the gaps.

However, if it is impermeable then water cannot pass through. This leads to increased surface runoff, which is the fastest way for rainfall to reach the river. Therefore, if the drainage basin is impermeable then it tends to be a flashier hydrograph and a greater risk of flooding.

6 PRECIPITATION

Heavy rainfalls leads to steep rising limbs and short lag times. Water is not given time to infiltrate thoroughly. This is why in deserts dried up rivers quickly replenish after a heavy storm (flash floods).

Conversely, light rains favours gradual and thorough infiltration, hence less water reaches the river. This results in long lag times.

QUICK FACT

A hydrograph is an important tool used by civil engineers to help them understand how water flows through a particular area. By studying the shape of a hydrograph, they can identify areas where and when flooding may occur and take steps to prevent it.

UNIT HYDROGRAPH

Unit Hydrograph essentially a tool for determining the direct runoff (DRO) response to rainfall. Once the watershed's response to one storm known, what its response for another will look like can be predicted.

Basic assumptions to generate unit hydrograph:

- The effective rainfall is uniformly distributed within its duration.
- The effective rainfall is uniformly distributed over the whole drainage basin
- The base duration of direct runoff hydrograph (DRH) due to an effective rainfall of unit duration is constant.
- The ordinates of DRH are directly proportional to the total amount of direct runoff of each hydrograph
- For a given basin, the runoff hydrograph due to a given period of rainfall reflects all the combined physical characteristics of basin (time-invariant)

PROCEDURE TO DERIVE UNIT HYDROGRAPH

- Plot the hydrograph.
- Separate the baseflow.
- Calculate the total volume of direct flow and the Equivalent Runoff Depth.
- Calculate the ordinates of unit hydrograph by dividing each direct flow with runoff depth.
- Plot the Unit Hydrograph (UH).

APPLICATION OF UNIT HYDROGRAPH

Unit Hydrograph can serve the following purposes:

1 RUNOFF PREDICTION

The unit hydrograph is used to predict the runoff response of a watershed to a specific amount of rainfall over a given duration.

2 HYDROLOGICAL ANALYSIS

It serves as a fundamental tool for hydrologists to analyze and understand the runoff characteristics of a catchment.

3 FLOOD FORECASTING

Unit hydrographs aid in forecasting and managing floods by providing insights into the timing and magnitude of peak flows.

4 INFRASTURCTURE DESIGN

Engineers use unit hydrographs to design water-related infrastructure such as stormwater management systems and reservoirs.

5 WATER RESOURCE MANAGEMENT

It contributes to effective water resource management by assisting in the assessment of water availability and distribution in a watershed.

EXAMPLE 4.1

A hydrograph is a graphical presentation of runoff rate against time.

- Calculate the direct runoff hydrograph using the data as tabulated below. (Assume 100 m^3/s as the baseflow).

- Identify the unit hydrograph. (Use area 80 km^2)

TIME	OBSERVED HYDROGRAPH
0	200
1	100
2	400
3	700
4	1000
5	800
6	600
7	400
8	200
9	100
10	100

EXAMPLE 4.1

A hydrograph is a graphical presentation of runoff rate against time.

- Calculate the direct runoff hydrograph using the data as tabulated below. (Assume 100 m^3/s as the baseflow).
- Identify the unit hydrograph. (Use area 80 km^2)

TIME	OBSERVED HYDROGRAPH
0	200
1	100
2	400
3	700
4	1000
5	800
6	600
7	400
8	200
9	100
10	100

Solution

TIME	OBSERVES HYDROGRAPH (m^3/s)	BASEFLOW (m^3/s)	DIRECT RUNOFF HYDROGRAPH (m^3/s)	UH-1H (m^3/s per cm)
0	200	100	100	6.25
1	100	100	0	0
2	400	100	300	18.75
3	700	100	600	37.50
4	1000	100	900	56.25
5	800	100	700	43.75
6	600	100	500	31.25
7	400	100	300	18.75
8	200	100	100	6.25
9	100	100	0	0
10	100	100	0	0
Total Q (m^3/s)			3500	

Volume of DRO = 3500 m^3/s x 1h x 60 min x 60 sec
= 1.26×10^7 m^3

Runoff depth = Volume of DRO/ Catchment area
= 1.26×10^7 m^3 / 80×10^6 m^2
= 0.16 m @ 16 cm

Runoff depth = Effective Rainfall
Unit hydrograph = Volume of DRO / Effective Rainfall

TUTORIAL

1

Table below shows the discharge for Sungai Buloh with 100km² area. If the base flow is 10m³/s, calculate the ordinates of unit hydrograph (UH) for the catchment.

TIME (hour)	DISCHARGE (m^3/s)
0	0
2	20
4	40
6	60
8	80
10	120
12	100
14	80
16	60
18	40
20	20

2

The discharge of river at 4 hour interval is shown in the Table 4.1 below. The catchment area is 600km². If the base flow is 40 m^3/s, determine the:

- Volume of direct runoff
- Effective Rain
- Ordinate of UH-4hr

Answer : V = 24.19 x $10^6 m^3$, D = 4cm

UNIT HYDROGRAPH CONVERSION

Unit Hydrograph essentially a tool for determining the direct runoff (DRO) response to rainfall. Once the watershed's response to one storm known, what its response for another will look like can be predicted.

Basic assumptions to generate unit hydrograph:

- The effective rainfall is uniformly distributed within its duration.
- The effective rainfall is uniformly distributed over the whole drainage basin
- The base duration of direct runoff hydrograph (DRH) due to an effective rainfall of unit duration is constant.
- The ordinates of DRH are directly proportional to the total amount of direct runoff of each hydrograph
- For a given basin, the runoff hydrograph due to a given period of rainfall reflects all the combined physical characteristics of basin (time-invariant)

UNIT HYDROGRAPH CONVERSION METHOD

Two method used to convert new unit hydrograph from current unit hydrograph are as follow:

1. SUPERPOSITION
2. S CURVE

SUPERPOSITION METHOD

If a D-h unit hydrograph is available and it is desired to develop a unit hydrograph of nDh, where n is an integer, it is easily accomplished by superposing n unit hydrograph with each graph separated from the previous on by D-h.

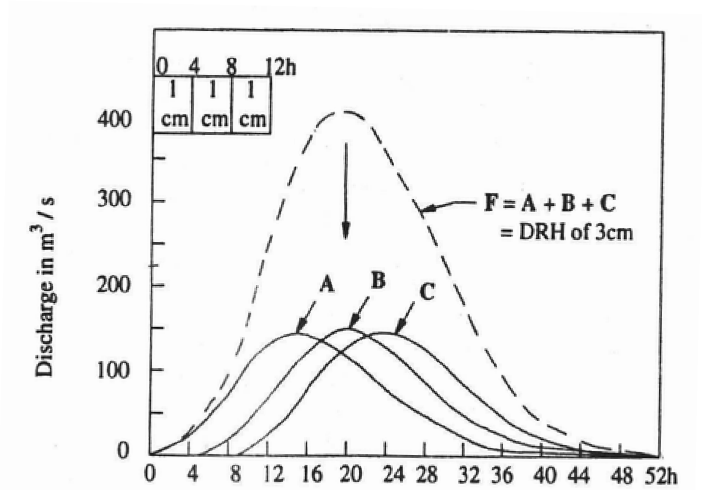

Figure 4.6 Method of superposition

SUPERPOSITION METHOD : PROBLEM SOLVING

EXAMPLE 4.2

Table 4.3, shows the 2h-UH for Sibu area. Estimate the ordinate 12h-UH by using superposition method.

TABLE 4.3

TIME	0	2	4	6	8	10	12	14	16	18	20
UH-2hr (m^3/s)	0	30	90	140	180	150	110	70	40	10	0

Solution

TIME	UH 2H (m^3/s)	LAGGED BY 2H	DIRECT FLOW (m^3/s)	UH 4h (m^3/s)
C1	**C2**	**C3**	**C4 = C2+C3**	**C5 = C5*(2H/4H)**
0	0	-	0	0
2	30	0	30	15
4	90	30	120	60
6	140	90	230	115
8	180	140	320	160
10	150	180	330	165
12	110	150	260	130
14	70	110	180	90
16	40	70	110	55
18	10	40	50	25
20	0	10	10	5
22	0	0	0	0
Total Q (m^3/s)	820			820

TUTORIAL

1 Table below, shows the 3h-UH from a catchment with the following ordinates. Estimate the ordinate 6h-UH by using superposition method.

TIME (hour)	UH-3H (m^3/s)
0	0
3	10
6	30
9	60
12	90
18	120
21	100
24	60
27	20
30	0

2 Table below shows ordinate of 6 hour unit hydrograph. By using superposition method, calculate the ordinates of 18 hour unit hydrograph for the same catchment.

TIME	0	6	12	18	24	30	36	42	48	54	60	66
UH-6hr (m^3/s)	0	20	60	150	120	90	66	50	32	20	10	0

S-CURVE METHOD

Also known as S-Hydrograph. It was produced by continuous effective rainfall at a constant rate for infinite period.

S-Curve was produced by summation of infinite series of D-h UH spaced D-h apart. It involves continually lagging D-h unit hydrograph by its duration and adding the ordinates.

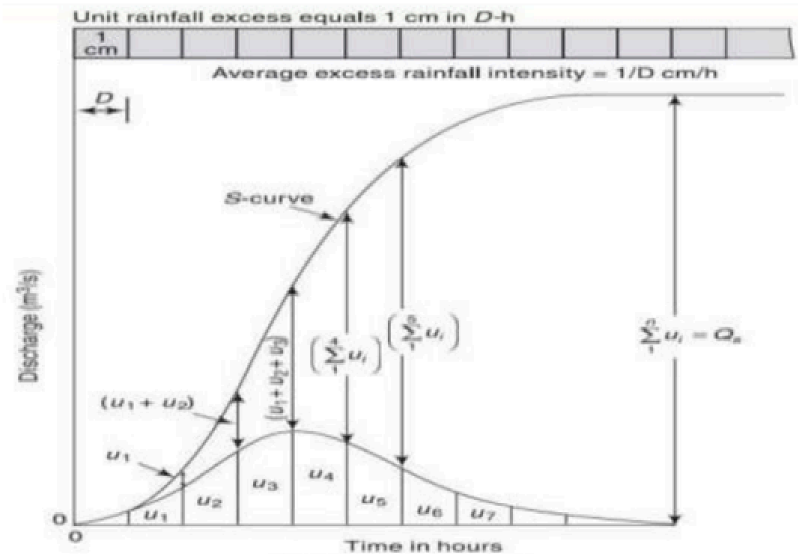

Figure 4.7 S-Hydrograph

S CURVE METHOD : PROBLEM SOLVING

EXAMPLE 4.3

Table 4.4 shows the ordinate of 2h-UH for Bintulu area. Estimate the ordinate UH-4h by using the S-curve method.

TABLE 4.4

TIME	0	2	4	6	8	10	12	14	16	18	20
UH-2hr (m^3/s)	0	30	90	140	180	150	110	70	40	10	0

Solution

TIME	UH 2H (m^3/s)	S-Curve (m^3/s)	S-Curve Offset (m^3/s)	Difference of S-Curve (m^3/s)	UH 4h (m^3/s)
C1	**C2**	**C3**	**C4**	**C5 = C3-C4**	**C6 = C5*2H/4H**
0	0	0	-	0	0
2	30	30	-	30	15
4	90	120	0	120	60
6	140	260	30	230	115
8	180	440	120	320	160
10	150	590	260	330	165
12	110	700	440	260	130
14	70	770	590	180	90
16	40	810	700	110	55
18	10	820	770	50	25
20	0	820	810	10	5
22	0	820	820	0	0
24	0	850	820	0	0
Total Q (m^3/s)	820				820

TUTORIAL

1 Table below shows the ordinate of 2h-UH for Bintulu area. Estimate the ordinate UH-6h by using the S-curve method.

TIME (hour)	UH-2H (m^3/s)
0	0
2	40
4	80
6	100
8	120
10	140
12	120
14	80
16	60
18	40
20	0

2 The daily stream flow data for a particular catchment having an area of 1200 km^2 are given in Table 4.5. Calculate:

- Direct runoff (using Simple straight lines method. Assume the base flow is 90m^3/s)
- Ordinate of UH-6h

TABLE 4.5

TIME	0	6	12	18	24	30	36	42	48	54	60
Discharge (m^3/s)	90	100	400	800	1000	700	500	300	200	100	90

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05

URBAN DRAINAGE DESIGN

Author:
MOHAMED BIN SAIM
SITI NUR FARHANA BINTI ABDUL AZIZ

DEFINITION OF STORMWATER

Streamflow or discharge, is the volume of water that moves over a designated point over a fixed of time. It is often expressed as cubic meter per second (m^3/S).

The flow of a stream is directly related to the amount of water moving off the watershed into the stream channel. It is affected by weather, increasing during rainstorms and decreasing during dry periods. It also changes during different seasons of the year, decreasing during the summer months when evaporation rates are high and shoreline vegetation is actively growing and removing water from the ground

PAST DRAINAGE ISSUE

In Malaysia, the traditional approach widely practiced to manage storm water design where allow developers to put in drains where appropriate. The engineers is only to determine drain size to comply with drainage system.

Urban drainage practice is based on 1975 DID Urban Drainage Design Manual, "Planning and Design Procedure No 1:Urban Drainage Design Standard For Peninsular Malaysia". Rapid disposal approach as adopted in this manual has led to increase in the occurance of flash floods as a result of increase in surface runoff, peak discharge, shorter flow duration and others. If the country continues to urbanize, the flood problem continue to increase.

Due to this problem, Department of Irrigation and Drainage (DID) is taking a proactive step by introducing New Urban Drainage Manual known as Storm Water management manual for Malaysia. Effective from January 2011, all new development in Malaysia must comply with this new guideline which control storm water from the aspect of quantity and quality runoff to achieve zero development impact contribution.

MSMA 2nd EDITION

MSMA 1st edition which was published in 2000 had include all the latest standard and practices, technologies, best engineering practices during that time. After 10 years of time lapse, new standard and practices, and technologies has evolve thus required new upgraded guideline. This improved version has been published by DID in MSMA 2nd Edition.

The MSMA 2nd Edition is developed through contributions from the Government as well as private sectors and experts. The manual has been simplified and updated to serve as a source of information and to provide guidance to the latest storm water best management practices (BMP'S).

The objectives of MSMA including to:

- Ensure the safety of the public
- Control nuisance flooding and provide for the safe passage of less frequent and larger flood events.
- Stabilize the landform and control erosion.
- Optimize the land available for urban development
- Minimize the environmental impact of urban runoff on water quality
- Enhance the urban landscape.

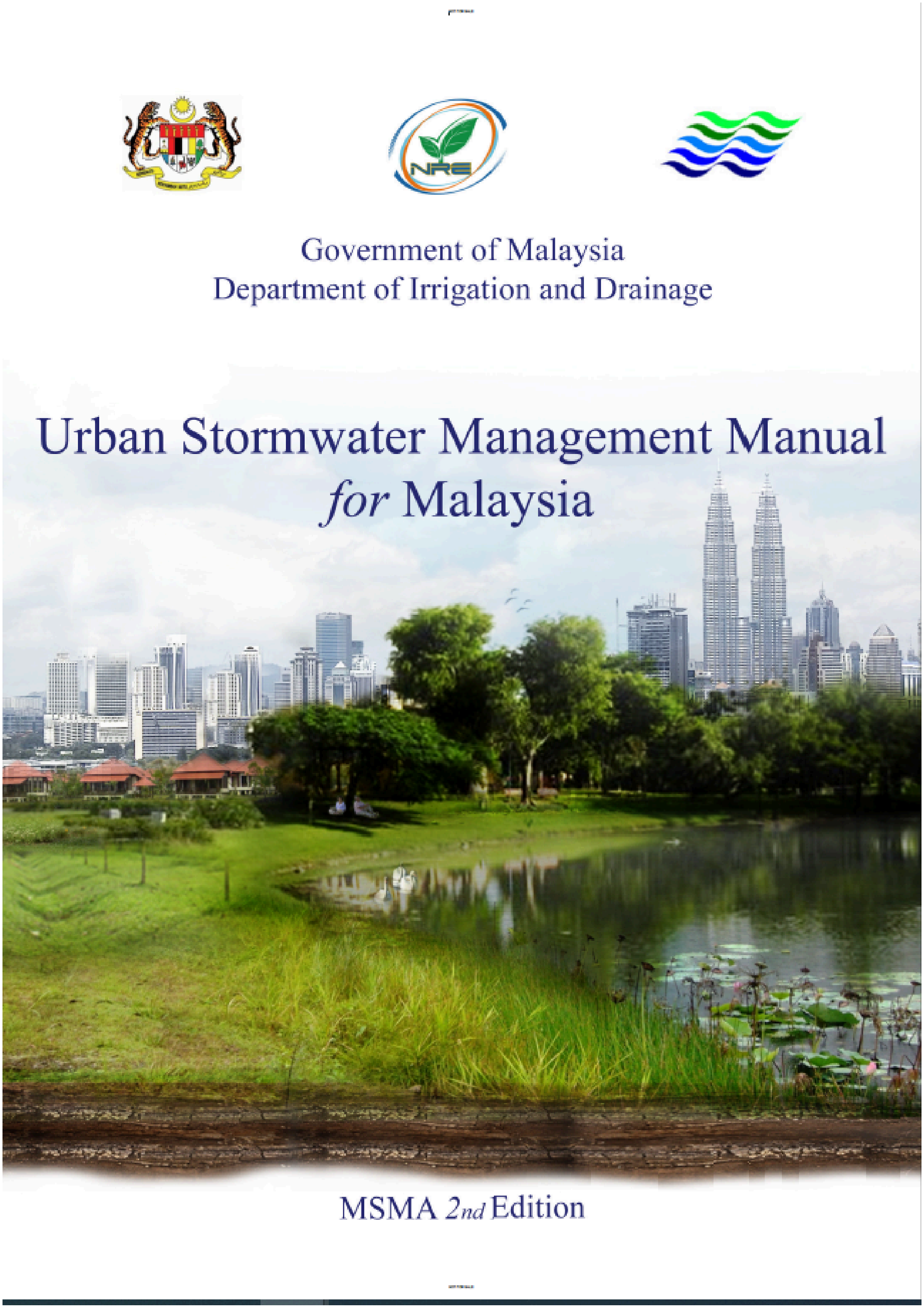

Figure 5.1 MSMA 2nd edition published by DID

MSMA 2nd EDITION

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STORMWATER QUANTITY DESIGN CRITERIA

1 DESIGN STORM ARI

An Annual Recurrence Interval (ARI) is an average number of years that is predicted will past before event of given magnitude.. For example, a 50 years ARI event would on an average happen every 50 years.

Design storm ARIs to be adopted for the planning and design of minor and major storm runoff quantity systems must follow requirement in Table 5.1.

Table 5.1 Design ARI based on type of development

Type of Development (See Note 1)	Minimum ARI (year) (See Note 2)	
	Minor System (See Note 3)	Major System (See Note 3)
Residential		
Bungalow and semi-detached dwellings	5	50
Link house/apartment	10	100
Commercial and business center	10	100
Industry	10	100
Sport field, park and agricultural land	2	20
Infrastructure/utility	5	100
Institutional building/complex	10	100

Notes:
1. For mixed developments, the highest of the applicable storm ARIs from the Table shall be adopted.
2. In the case where designing to the higher ARI would be impractical, the selection of appropriate ARI should be adjusted to optimise the cost to benefit ratio or social factors. If justified, a lower ARI might be adopted for the major system, with consultation and approval from the Department of Irrigation and Drainage (DID). Even if the stormwater system for the existing developed condition is designed for a lower ARI storm, sufficient land should be reserved for higher ARI flow rates, so that the system can be upgraded when the area is built up in the future.
3. All development projects shall be protected from both minor and major floods and, therefore, must have combination of minor and major systems. Habitable floor levels of the buildings (platform levels) shall be set above the 100 year ARI flood level based on the most recent data available. The drainage submission must show the minor and major system components in their drawings and plans.

The minor system is designed to collect, control and convey runoff from buildings, infrastructures and utilities in relatively frequent storm events to minimise inconvenience and nuisance flooding. Normally it is designed up to 10 year ARI. During any event larger than the minor storm ARI, the higher runoff will overspill the minor drainage components.

As it is designed generally up to 100 year ARI, the major system is intended to safely convey and control runoff collected by the minor drainage system together. Its possible overspill will flow to the larger downstream systems and nearby water bodies. The major system must protect the community from the consequences of large and reasonably rare storm events, which could cause severe property damage and injury or loss of life.

2 PEAK DISCHARGE CONTROL

Runoff quantity control for any type of development (proposed development, new development and redevelopment) must obey the following CRITERIA:

> **"Post development peak flow of any ARI at the project outlet must be less than or equal to the pre-development peak flow of the corresponding ARI ($Q_{post} \leq Q_{pre}$)".**

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NEW DEVELOPMENT

Defined as the conversion of natural or rural areas into urban, industrial infrastructure and/or utility development.

The post-development peak flow from the outlet point(s) of the site to the downstream drainage system shall not exceed the corresponding ARI pre-development flow for both the minor and major system design storm ARIs. Pre-development peak flow shall be the estimated flow from the site based on known or estimated catchment conditions prior to the new development.

REDEVELOPMENT

Defined as the renewal and reconstruction of an existing residential, commercial, industrial or infrastructure areas. The degree of runoff control required will depend on the scale of the development and the net increase in impervious area.

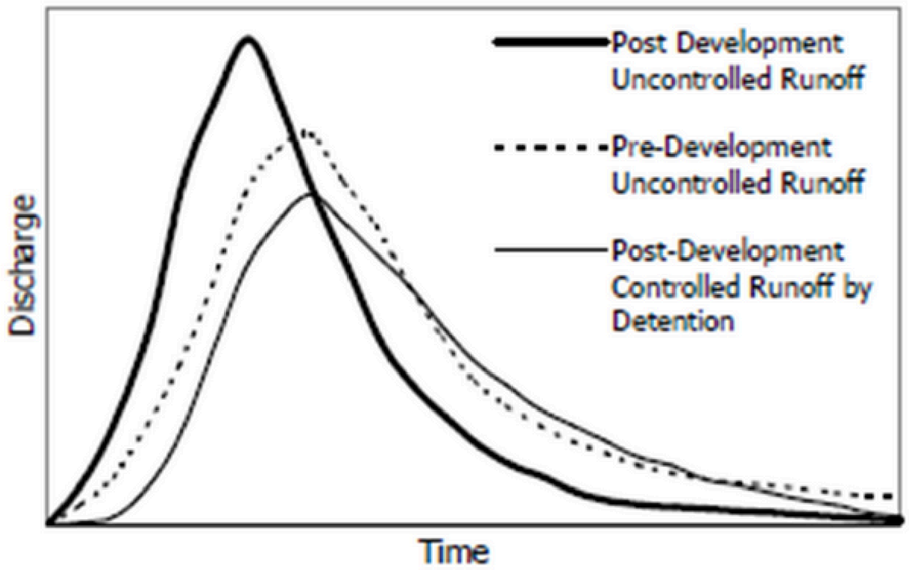


Figure 5.2 Runoff Quantity Control Post Development and Pre Development

3 STORAGE FACILITIES

Storage facilities are the core elements of achieving the major storm water quantity control criteria. Its achievable with proper locating and sizing of the storage facilities.

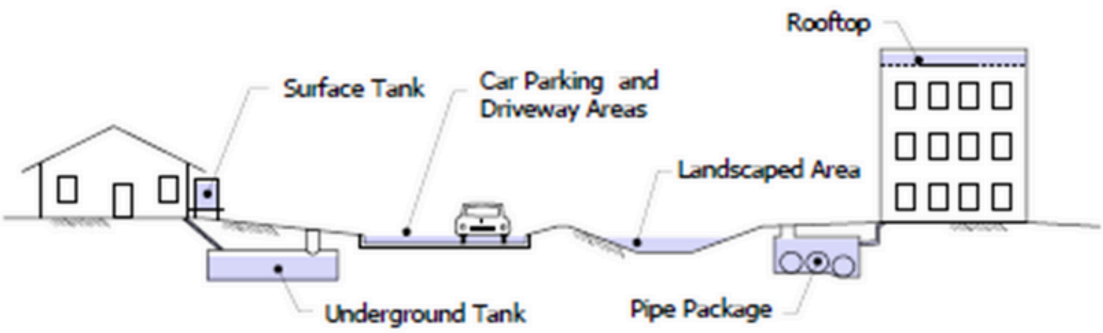


Figure 5.3 On-site Detention Pond

Storage facilities can be divided into two categories:

STORAGE FACILITIES

ON-SITE DETENTION

Above ground:
- can be located at roof top, lawns, garden, car park and driveways

Below ground:
- tanks and pipe package

Combination:
- combination of below ground storage and above ground storage

DETENTION POND

Dry type and Wet type

Criteria of pond to be considered:
- Degree of reduction of flows from the catchment.
- water depth in the pond
- pond empty time

4 CONVEYANCE FACILITIES

Storm water conveyance systems must be planned, analysed and designed in order to provide acceptable level of safety for the general public and protection for private and public property

PROPERTY DRAINAGE

System which transfer runoff from roofs, paved areas and other surfaces to a suitable outlet. The systems involves gutter, downpipes, drains, pipes, swales and treatment facilities.

PAVEMENT DRAINAGE

Effective pavement drainage is essential to the maintenance of road service level and to traffic safety. The potential for hydroplanning at a high speed as well as the potential for vehicles to float or be washed off road at lower speeds must be considered in designing pavement drainage.

OPEN DRAIN AND SWALES

Designing open drain and swales should considered space availability, site suitability, and environment conditions.

STORMWATER QUALITY DESIGN CRITERIA

Storm water quality control facilities must be planned, analysed and designed for all type of development based on the following criteria:

Table 5.2 Quality control design criteria

Variables	Criteria
Water Quality Volume	Temporary BMPs - 50mm of rainfall applied to catchments draining to the BMPs. Permanent BMPs - 40mm of rainfall applied to catchments draining to the BMPs.
Primary Outlet Sizing	Based on the peak flow calculated from the 3 month ARI event
Secondary Outlet (Spillway) Sizing	As per the ARIs recommended in the respective chapters of the individual BMPs.

The function of temporary Best Management Practice (BMP's) is to minimize erosion and soil delivery away from the developing or construction site as a result of land clearing and grading or other land-disturbing activities.

RAINFALL ESTIMATION

Rainfall data and characteristics are the important attributes in studying and designing storm water infrastructure. Adequacy and significant of the rainfall data is a pre-requisite for designing urban water and storm water management projects.

1 TIME OF CONCENTRATION

Time of Concentration (tc) is the travel time of runoff flows from the upstream in the contributing catchment area to the point under consideration downstream. Time of concentration is very important in storm water drainage design as it is directly related to peak flow rate.

tc can be obtain using the following formula:

$$t_c = t_o + t_g \quad (22)$$

where,

tc = Time of concentration (min)
to = Time of the overland flow time (min)
tg = Time of travel in street gutter (min)

tc can also be obtain using the formula 23 in designing storm water drainage:

$$t_c = t_o + t_d \quad (23)$$

where,

tc = Time of concentration (min)
to = Time of the overland flow time (min)
td = Time of travel in roadsides swales, drain, channel and small streams (min)

The value of to and tg or td can be obtained using formula in the table 5.3

Table 5.3 Equation to estimate Time of Concentration
(QUDM, 2007)

Travel Path	Travel Time	Remark
Overland Flow	$t_o = \dfrac{107.n^{*}.L^{1/3}}{S^{1/5}}$	t_o = Overland sheet flow travel time (minutes) L = Overland sheet flow path length (m) *for Steep Slope (>10%), L ≤ 50 m* *for Moderate Slope (<5%), L ≤ 100 m* *for Mild Slope (<1%), L ≤ 200 m* n^{*} = Horton's roughness value for the surface (Table 2.2) S = Slope of overland surface (%)
Curb Gutter Flow	$t_g = \dfrac{L}{40\sqrt{S}}$	t_g = Curb gutter flow time (minutes) L = Length of curb gutter flow (m) S = Longitudinal slope of the curb gutter (%)
Drain Flow	$t_d = \dfrac{n.L}{60R^{2/3}S^{1/2}}$	n = Manning's roughness coefficient (Table 2.3) R = Hydraulic radius (m) S = Friction slope (m/m) L = Length of reach (m) t_d = Travel time in the drain (minutes)

Calculation of tc is subject to the catchment properties such as length, slope and roughness of the drainage path. Typical value of Horton's Value can be obtained from table 5.4.

Table 5.4 Value of Horton's roughness n*
(QUDM, 2007)

Land Surface	Horton's Roughness n^*
Paved	0.015
Bare Soil	0.0275
Poorly Grassed	0.035
Average Grassed	0.045
Densely Grassed	0.060

Note that travel path using drain flow, hydraulic radius and drain slope must be obtain first. Equation for hydraulic radius based on drain shape, and manning's coefficient can be referred in table 5.5 and table 5.6 respectively.

Table 5.5 Hydraulic radius for different shape of drain

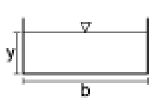
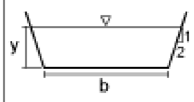
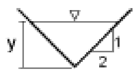
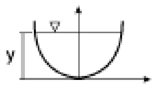
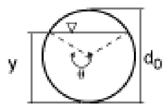
Channel type	Area A	Wetted permiter P	Hydraulic radius R	Top width T	Hydraulic depth D
	by	b+2y	$\frac{by}{b+2y}$	b	y
	b+2y	$b+2y\sqrt{1+z^2}$	$\frac{(b+zy)y}{b+2y\sqrt{1+z^2}}$	b+2zy	$\frac{(b+zy)y}{b+2zy}$
	zy^2	$2y\sqrt{1+z^2}$	$\frac{zy}{2\sqrt{1+z^2}}$	2zy	$\frac{1}{2}y$
	$\frac{2}{3}Ty$	$T+\frac{8}{3}\frac{y^2}{T}$	$\frac{2T^2y}{3T^2+8y^2}$	$\frac{3}{2}\frac{A}{y}$	$\frac{2}{3}y$
	$\frac{1}{8}(\theta - \sin\theta)$	$\frac{1}{2}\theta d_0$	$\frac{1}{4}\left[1-\frac{\sin\theta}{\theta}\right]d_0$	$2\sqrt{y(d_0-y)}$	$\frac{1}{8}\left(\frac{\theta - \sin\theta}{\sin\frac{\theta}{2}}\right)d_0$

Table 5.6 Value of Manning's roughness Coefficient (n)

(Chow, 1959; DID, 2000; and French, 1985)

Drain/Pipe	Manning Roughness n
Grassed Drain	
Short Grass Cover (< 150 mm)	0.035
Tall Grass Cover (≥ 150 mm)	0.050
Lined Drain	
Concrete	
Smooth Finish	0.015
Rough Finish	0.018
Stone Pitching	
Dressed Stone in Mortar	0.017
Random Stones in Mortar or Rubble Masonry	0.035
Rock Riprap	0.030
Brickwork	0.020
Pipe Material	
Vitrified Clay	0.012
Spun Precast Concrete	0.013
Fibre Reinforced Cement	0.013
UPVC	0.011

2 EMPIRICAL IDF CURVE

Empirical equation can be used to minimise error in estimating the rainfall intensity values for the IDF curve. It is expressed as:

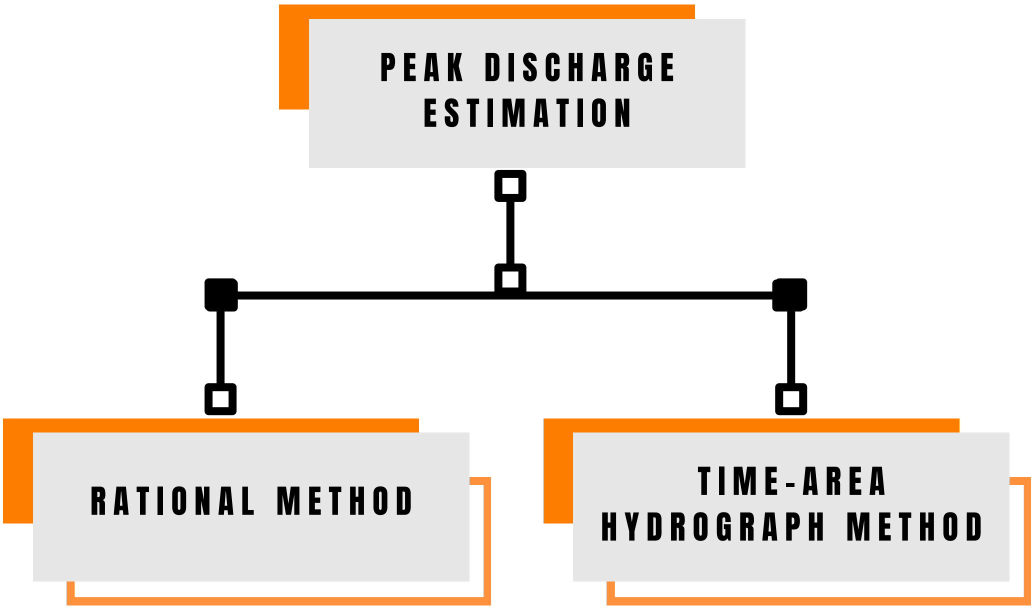
$$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}} \tag{24}$$

where,

i = Average rainfall intensity (mm/hr)
T = Average recurrence interval (ARI)
d = Storm duration (hour)
λ, κ, θ and η = Fitting constant (refer Appendix A-1 and A-2)

3 PEAK DISCHARGE ESTIMATION

Peak runoff discharge can be estimate using two different method:



The Rational Method is the most frequently used technique for runoff peak estimation in Malaysia and many parts of the world. It gives satisfactory results for small drainage catchments and is expressed as:

$$Q = \frac{C.i.A}{360} \qquad (25)$$

where,

Q = Peak flow (m^3/s);
C = Runoff coefficient (Table 5.7);
i = Average rainfall intensity (mm/hr); and
A = Drainage area (ha).

Table 5.7 Recommended runoff coefficient for various landuse
(DID, 1980; Chow et. al., 1988; QUDM, 2007; and Darwin Harbour, 2009)

Landuse	Runoff Coefficient (C)	
	For Minor System (≤10 year ARI)	For Major System (> 10 year ARI)
Residential		
Bungalow	0.65	0.70
Semi-detached Bungalow	0.70	0.75
Link and Terrace House	0.80	0.90
Flat and Apartment	0.80	0.85
Condominium	0.75	0.80
Commercial and Business Centres	0.90	0.95
Industrial	0.90	0.95
Sport Fields, Park and Agriculture	0.30	0.40
Open Spaces		
Bare Soil (No Cover)	0.50	0.60
Grass Cover	0.40	0.50
Bush Cover	0.35	0.45
Forest Cover	0.30	0.40
Roads and Highways	0.95	0.95
Water Body (Pond)		
Detention Pond (with outlet)	0.95	0.95
Retention Pond (no outlet)	0.00	0.00

Note: The runoff coefficients in this table are given as a guide for designers. The near-field runoff coefficient for any single or mixed landuse should be determined based on the imperviousness of the area.

RUNOFF COEFFICIENT FOR MIXED DEVELOPMENT

Segment of different land use within a sub-catchment can be combined to produce an average runoff coefficient. For example, if a sub-catchment consist of segments with different landuse denoted by i= 1,2,...,n; the average coefficient is estimated by the following equation:

$$C_{avg} = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i} \quad (26)$$

where,

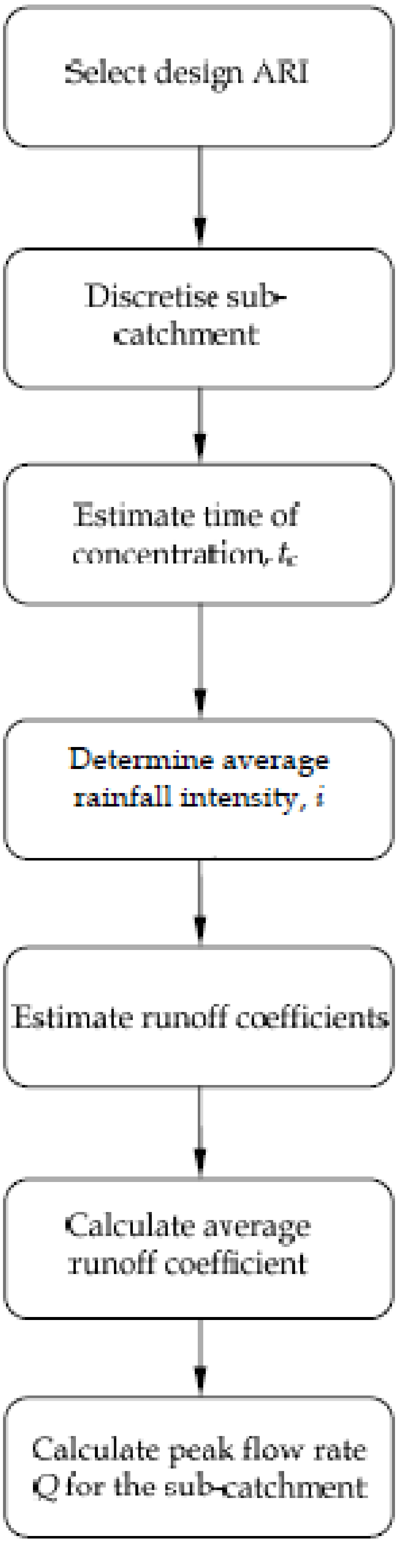
Cavg = Average runoff coefficient;
Ci = Runoff coefficient for segment i;
Aj = Area of segment i (ha); and
n = total number of segments

ASSUMPTIONS

Assumptions used in the Rational Method are as follows:

- The peak discharge occurs when the entire catchment is contributing to the flow;
- The rainfall intensity is uniform over the entire catchment area; and
- The rainfall intensity is uniform over a time duration equal to the time of concentration; tc.

CALCULATION STEPS



- Select design ARI for the catchment

- Divide sub-catchment into segment of similar land use or surface slope

- Estimate overland flow time
- Estimate flow times for all other flow components.
- Use equation from table 5.3

- Calculate i for design ARI and d is equal to time of concentration in hour.
- Fitting constant can be obtained from Appendix A-1 and A-2

- Estimate C value for each segment if there were any different in landuse from table 5.7

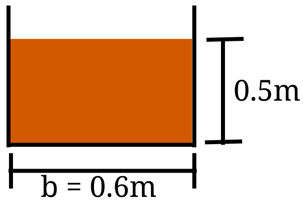
- Estimate Cavg value for the catchment by using equation 26

- Calculate peak flow using equation 25 and all the attribute obtain from the above step.

EXAMPLE 5.1

From the data below, estimate peak discharge for catchment area at Ampang using smooth lined drain 500 mm depth and 600 mm width.

Data	Sub catchment A	Sub catchment B
Drainage system	Minor	Major
Land use (Develop area) (ha)	Bungalow – 10.7 ha	Commercial – 25 ha
Land use (Undeveloped area) (ha)	Average grass surface – 3.2 ha	Poor grass surface – 4.96 ha
Length of overland flow (m)	20.3	53.2
Land slope (%)	2.8	3.9
Length of drain (m)	255	350
Drain slope (m/m)	4/255	5/350



Solution

STEP 1: <u>Select design ARI from Table 5.1</u>

Based on type of development and drainage system, minimum year of ARI can be obtained from table 5.1.

Sub-Catchment	Type of Development	Drainange System	**Minimum (year)**
A	Bungalow	Minor	**5**
B	Commercial	Major	**100**

TABLE 5.1 Design ARI based on type of development

Type of Development (See Note 1)	Minimum ARI (year) (See Note 2)	
	Minor System (See Note 3)	Major System (See Note 3)
Residential		
Bungalow and semi-detached dwellings	5	50
Link house/apartment	10	100
Commercial and business center	10	100
Industry	10	100
Sport field, park and agricultural land	2	20
Infrastructure/utility	5	100
Institutional building/complex	10	100

Notes: 1. For mixed developments, the highest of the applicable storm ARIs from the Table shall be adopted.

2. In the case where designing to the higher ARI would be impractical, the selection of appropriate ARI should be adjusted to optimise the cost to benefit ratio or social factors. If justified, a lower ARI might be adopted for the major system, with consultation and approval from the Department of Irrigation and Drainage (DID). Even if the stormwater system for the existing developed condition is designed for a lower ARI storm, sufficient land should be reserved for higher ARI flow rates, so that the system can be upgraded when the area is built up in the future.

3. All development projects shall be protected from both minor and major floods and, therefore, must have combination of minor and major systems. Habitable floor levels of the buildings (platform levels) shall be set above the 100 year ARI flood level based on the most recent data available. The drainage submission must show the minor and major system components in their drawings and plans.

STEP 2: <u>Discretise Sub-Catchment</u>

This question already discretise the whole catchment into two sub-catchment.

Sub-Catchment	Type of Development	Drainange System
A	Bungalow	Minor
B	Commercial	Major

STEP 3: Estimate Time of Concentration, tc

Using equation 23:

$$t_c = t_o + t_d \qquad (23)$$

1. *Estimate Overland flow Time; t_o*

From table 5.3, equation for t_o as follow

$$t_o = \frac{107 . n^* . L^{1/3}}{S^{1/5}}$$

From Table 5.4: Values of Horton's Roughness; n*.

SUB-CATCHMENT	LENGTH OF OVELAND FLOW (m)	LAND SLOPE (%)	n*	t_o (min)
A	20.3	2.8	0.045	10.688
B	53.2	3.9	0.035	10.727

t_o for Sub catchment A,

$$t_o = \frac{107(0.045)(20.3)^{1/3}}{(2.8)^{1/5}}$$

$$t_o = \frac{13.135}{1.229}$$

t_o = 10.688 minutes

t_o for Sub catchment B,

$$t_o = \frac{107(0.035)(53.2)^{1/3}}{(3.9)^{1/5}}$$

$$t_o = \frac{14.085}{1.313}$$

t_o = 10.727 minutes

2. Estimate Drain flow Time; td

From table 5.3, equation for td as follow

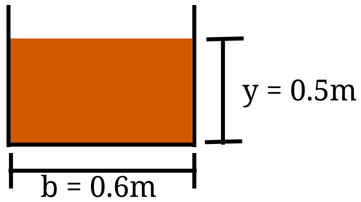
$$td = \frac{n.L}{60R^{2/3}S^{1/2}}$$

From Table 5.6: Values of Manning's Roughness Coefficient; n.

SUB-CATCHMENT	LENGTH OF DRAINAGE (m)	DRAIN SLOPE	n	*td* (min)
A	255	4/255	0.015	1.536
B	350	5/350	0.015	2.253

Note: Using smooth lined drain.

Drain size: 500 mm depth x 600 mm width



Drain Area; A = (0.5 x 0.6) m^2

= 0.3 m^2

Drain Wetted Parameter; P

= [0.6 + 2(0.5)] m

= [0.6 + 1.0] m

= 1.6 m

Hydraulics Radius; R = A/P

= 0.3/1.6

= 0.188 m

td for Sub catchment A,

$$t_d = \frac{(0.015)(255)}{60(0.188)^{2/3}(0.016)^{1/2}}$$

$$t_d = \frac{3.825}{2.491}$$

t_o = 1.536 minutes

td for Sub catchment B,

$$t_d = \frac{(0.015)(350)}{60(0.188)^{2/3}(0.014)^{1/2}}$$

$$t_d = \frac{5.250}{2.330}$$

t_o = 2.253 minutes

Therefore;

By using equation 23, tc for this question are as follows:

SUBCATCHMENT	t_o (min)	*td* (min)	*tc* (min)
A	10.688	1.536	**12.224**
B	10.727	2.253	12.980

(Note: Take the shortest tc to consider d value as it give higher peak flow. Drainage system must be designed using maximum peak flow to avoid under-design.)

Thus, Time of Concentration, tc = 12.224 min

STEP 4: Determine Average Rainfall Intensity, i

To calculate i, we must have design ARI and duration; d (time of concentration), and fitting constant from IDF data for corresponding location.

Study location = Ampang, Selangor
Rainfall Station = JPS Ampang
ARI, T = High ARI for both sub catchment (5 and 100y)

Thus appendix A1 to be referred.

Selangor	1	2815001	JPS Sungai Manggis	56.052	0.152	0.194	0.857
	2	2913001	Pusat Kwln. JPS T Gong	63.493	0.170	0.254	0.872
	3	2917001	Setor JPS Kajang	59.153	0.161	0.118	0.812
	4	3117070	JPS Ampang	65.809	0.148	0.156	0.837
	5	3118102	SK Sungai Lui	63.155	0.177	0.122	0.842
	6	3314001	Rumah Pam JPS P Setia	62.273	0.175	0.205	0.841
	7	3411017	Setor JPS Tj. Karang	68.290	0.175	0.243	0.894
	8	3416002	Kg Kalong Tengah	61.811	0.161	0.188	0.816
	9	3516022	Loji Air Kuala Kubu Baru	67.793	0.176	0.278	0.854
	10	3710006	Rmh Pam Bagan Terap	60.793	0.173	0.185	0.884

CONSTANTS	VALUE
λ	65.809
K	0.148
ϴ	0.156
η	0.837

By using equation 24, rainfall intensity can be calculated

$$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}} \quad (24)$$

tc = 12.224 min

d = 12.980 /60

= 0.204 hr

Therefore,

$$i = \frac{(65.809)(100)^{0.148}}{(0.204 + 0.156)^{0.837}}$$

$$i = \frac{130.102}{0.425}$$

i = 306.12 mm/hr

STEP 5: Estimate runoff coefficient, c

Obtain runoff coefficient for each sub-catchment from Table 5.7: Recommended Runoff Coefficients for Various Land uses; C.

Sub-Catchment A

TYPE OF DEVELOPMENT	AREA (ha)	RUNOFF COEFF;
DEVELOPED AREA	10.7	0.65
UNDEVELOPED AREA	3.2	0.40

Sub-Catchment B

TYPE OF DEVELOPMENT	AREA (ha)	RUNOFF COEFF;
DEVELOPED AREA	25	0.95
UNDEVELOPED AREA	4.96	0.60

STEP 6: Calculate average runoff coefficient, Cavg

Obtain average runoff coefficient by using equation 26

$$C_{avg} = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i} \tag{26}$$

STEP 6: Calculate average runoff coefficient, Cavg

Obtain average runoff coefficient by using equation 26

$$C_{avg} = \frac{\sum_{i=1}^{n} C_i\, A_i}{\sum_{i=1}^{n} A_i} \quad (26)$$

Sub-Catchment A

$$\text{C average Sub Catchment A} = \frac{\text{(C DEVELOPED x A DEVELOPED) + (C UNDEVELOP x A UNDEVELOP)}}{\sum(A\ DEVELOPED + A\ UNDEVELOP)}$$

$$\text{C average Sub Catchment A} = \frac{(0.65 \times 10.7) + (0.40 \times 3.2)}{(10.7 + 3.2)}$$

C average = **0.592**

Sub-Catchment B

$$\text{C average Sub Catchment A} = \frac{\text{(C DEVELOPED x A DEVELOPED) + (C UNDEVELOP x A UNDEVELOP)}}{\sum(A\ DEVELOPED + A\ UNDEVELOP)}$$

$$\text{C average Sub Catchment B} = \frac{(0.95 \times 25) + (0.60 \times 4}{(25 + 4.96)}$$

C average = **0.892**

STEP 7: Calculate peak flow rate for Q

Obtain peak flow rate by using equation 25

$$Q = \frac{C.i.A}{360} \quad (25)$$

$\sum C_{TOTAL} = [C_{AVG}.\ A_{TOTAL}]_A + [C_{AVG}.\ A_{TOTAL}]_B\ m^2$

$= [0.592 \times 13.900] + [0.892 \times 29.960]\ m^2$

$= [8.229 + 26.724]\ m^2$

$= \mathbf{34.953\ m^2}$

Intensity; i = **306.12 mm/hr**

Thus, peak discharge is

$$Q = \frac{(34.953 \times 306.12)}{360}$$

$$Q = \mathbf{29.72\ m^3/s}$$

EXAMPLE 5.2

One commercial area with 10 hectares is developed in Ladang Kekayaan at Johor. Major drainage system is built to avoid flood using concrete rough finish lined drain. Assume that length of overland flow is 100 m, length of drain is 350m with drain slope 5/350 and hydraulic radius 0.1875. Average land slope for that area is 1% and land use for undeveloped area is 3 hectares with poor grass surface.

a) Calculate time of concentration, tc
b) Calculate peak discharge for the catchment area, Qp

Solution

a) Calculate time of concentration, tc

1. *Estimate Overland flow Time;* t_o

From table 5.3, equation for t_o as follow

$$t_o = \frac{107.n^*.L^{1/3}}{S^{1/5}}$$

From Table 5.4: Values of Horton's Roughness; n*.

LENGTH OF OVELAND FLOW (m)	LAND SLOPE (%)	n*	t_o (min)
100	1	0.035	**17.38**

$$t_o = \frac{107(0.035)(100)^{1/3}}{(1)^{1/5}}$$

$$t_o = \frac{17.38}{1}$$

t_o = 17.38 minutes

2. Estimate Drain flow Time; td

From table 5.3, equation for td as follow

$$td = \frac{n.L}{60R^{2/3}S^{1/2}}$$

From Table 5.6: Values of Manning's Roughness Coefficient; n.

LENGTH OF DRAINAGE (m)	DRAIN SLOPE	n	R	*td* (min)
350	5/350	0.018	0.1875	**2.70**

Note: Using concrete rough finish drain.

$$t_d = \frac{(0.018)(350)}{60(0.1875)^{2/3}(0.014)^{1/2}}$$

$$t_d = \frac{6.3}{2.33}$$

td = 2.70 minutes

Using equation 23,

$$t_c = t_o + t_d \qquad (23)$$

tc = 17.38 + 2.70
 = 20.08 min

b) Calculate peak discharge, Qp

Obtain peak flow rate by using equation 25

$$Q = \frac{C.i.A}{360} \qquad (25)$$

Calculate average runoff coefficient, Cavg

Obtain average runoff coefficient by using equation 26

$$C_{avg} = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i} \quad (26)$$

TYPE OF DEVELOPMENT	AREA (ha)	RUNOFF COEFF;
DEVELOPED AREA *(Commercial)*	10	0.95
UNDEVELOPED AREA *(Grass Cover)*	3	0.50

(Note: Major drainage system)

$$\text{C average} = \frac{(\text{C DEVELOPED x A DEVELOPED}) + (\text{C UNDEVELOP x A UNDEVELOP})}{\sum(A\ DEVELOPED + A\ UNDEVELOP)}$$

$$\text{C average} = \frac{(0.95 \times 10) + (0.50 \times 3)}{(10 + 3)}$$

C average = 0.846

→ Determine Average Rainfall Intensity, i

To calculate i, we must have design ARI and duration; d (time of concentration), and fitting constant from IDF data for corresponding location.

Study location = Ladang Kekayaan, Johor
Rainfall Station = Ladang Kekayaan

To obtain fitting constant, ARI must first be assumed.

Based on type of development and drainage system, minimum year of ARI can be obtained from table 5.1.

Type of Development (See Note 1)	Minimum ARI (year) (See Note 2)	
	Minor System (See Note 3)	Major System (See Note 3)
Residential		
Bungalow and semi-detached dwellings	5	50
Link house/apartment	10	100
Commercial and business center	10	100
Industry	10	100
Sport field, park and agricultural land	2	20
Infrastructure/utility	5	100
Institutional building/complex	10	100

Notes: 1. For mixed developments, the highest of the applicable storm ARIs from the Table shall be adopted.

2. In the case where designing to the higher ARI would be impractical, the selection of appropriate ARI should be adjusted to optimise the cost to benefit ratio or social factors. If justified, a lower ARI might be adopted for the major system, with consultation and approval from the Department of Irrigation and Drainage (DID). Even if the stormwater system for the existing developed condition is designed for a lower ARI storm, sufficient land should be reserved for higher ARI flow rates, so that the system can be upgraded when the area is built up in the future.

3. All development projects shall be protected from both minor and major floods and, therefore, must have combination of minor and major systems. Habitable floor levels of the buildings (platform levels) shall be set above the 100 year ARI flood level based on the most recent data available. The drainage submission must show the minor and major system components in their drawings and plans.

ARI can be assumed as 100 years

By using appendix A-1, fitting constant for Ladang Kekayaan, Johor are as follow:

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Johor	1	1437116	Stor JPS Johor Bahru	59.972	0.163	0.121	0.793
	2	1534002	Pusat Kem. Pekan Nenas	54.265	0.179	0.100	0.756
	3	1541139	Johor Silica	59.060	0.202	0.128	0.660
	4	1636001	Balai Polis Kg Seelong	50.115	0.191	0.099	0.763
	5	1737001	SM Bukit Besar	50.554	0.193	0.117	0.722
	6	1829002	Setor JPS Batu Pahat	64.099	0.174	0.201	0.826
	7	1834124	Ladang Ulu Remis	55.864	0.166	0.174	0.810
	8	1839196	Simpang Masai K. Sedili	61.562	0.191	0.103	0.701
	9	1931003	Emp. Semberong	60.568	0.163	0.159	0.821
	10	2025001	Pintu Kaw. Tg. Agas	80.936	0.187	0.258	0.890
	11	2033001	JPS Kluang	54.428	0.192	0.108	0.740
	12	2231001	Ladang Chan Wing	57.188	0.186	0.093	0.777
	13	2232001	Ladang Kekayaan	53.457	0.180	0.094	0.735
	14	2235163	Ibu Bekalan Kahang	52.177	0.186	0.055	0.652
	15	2237164	Jalan Kluang-Mersing	56.966	0.190	0.144	0.637
	16	2330009	Ladang Labis	45.808	0.222	0.012	0.713
	17	2528012	Rmh. Tapis Segamat	45.212	0.224	0.039	0.711
	18	2534160	Kg Peta Hulu Sg Endau	59.500	0.185	0.129	0.623
	19	2636170	Setor JPS Endau	62.040	0.215	0.103	0.592

CONSTANTS	VALUE
λ	53.457
K	0.180
ϴ	0.094
η	0.735

By using equation 24, rainfall intensity can be calculated

$$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}} \quad (24)$$

tc = 20.08 min
d = 20.08 /60
= 0.33 hr

Therefore,

$$i = \frac{(53.457)(100)^{0.180}}{(0.33+0.094)^{0.735}}$$

$$i = \frac{130.102}{0.425}$$

i = 230.19 mm/hr

Thus, peak discharge is

$$Q = \frac{(0.592\ x\ (10+3)\ x\ 230.19)}{360}$$

Q = 4.92 m³/s

TUTORIAL

1 Table below, shows the catchment data for an urban area in Alor Setar. A 0.35 m depth and 0.60 m width concrete smooth finish lined drain will be built in that area to accommodate the stormwater for 20 years Average Recurrence Interval (ARI).

Data	Sub catchment A	Sub catchment B
Drainage system	Major	Minor
Land use (Develop area) (ha)	Commercial 25 ha	Apartment 25 ha
Land use (Undeveloped area) (ha)	Average grass surface 75	Bare Soil 10.22
Length of overland flow (m)	45	52
Land slope (%)	3.5	12.9
Length of drain (m)	80	127
Drain slope (m/m)	5/350	3/450

2 An area located at Kuala Krai, Kelantan has a data as shown in Table 5.8. A concrete rectangular channel with a rough finishing of 500mm depth and 400mm width is placed in that area to accommodate the stormwater discharge for sub-catchment A and sub-catchment B. By using rainfall data from JPS Kuala Krai Rainfall Station:

a) Determine the time of concentration, tc
b) Calculate peak discharge, Qp generate from a major system.

TUTORIAL

TABLE 5.8

Data	Sub catchment A	Sub catchment B
Drainage system	Major	Major
Land use (Develop area) (ha)	Business Centre 23.8	Apartment 15.45
Land use (Undeveloped area) (ha)	Average Grassed cover 7.11	Bare Soil 6.96
Length of overland flow (m)	70.6	82.9
Land slope (%)	2.8	12.9
Length of drain (m)	285	730
Drain slope	0.03	0.07

3 Commercial development of 30 hectares in Bukit Bentong, Pahang is proposed to be developed. The undeveloped area is 5 hectares with poorly grassed. The post-development time of concentration, tc at the development outlet is estimated to be 18.70 minutes and Average Runoff Coefficient, C is 0.8286. Determine the peak flow of rectangular drain to accomodate a 10 year ARI minor system design.

This method assumes that the discharge hydrograph for any storm is characterised by separable sub-catchment translation and storage effects. Pure translation of the direct runoff to the outlet via the drainage network is described using the drainage travel time, resulting in an discharge hydrograph that ignores storage effects.

To apply this method, a few step can be followed as listed:

STEP 1

Divide catchment into a number of isochrones or lines of equal travel time to the outlet as Figure 5.3

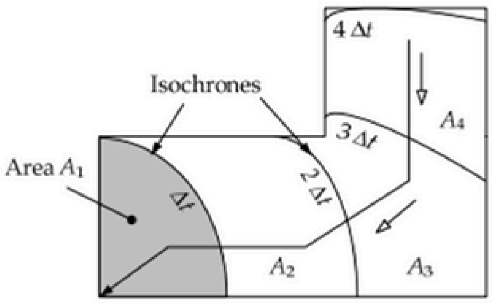


Figure 5.3 Catchment Isochrones

STEP 2

Determine the areas between isochrones and plot the value against travel time to outlet as shown in figure 5.4

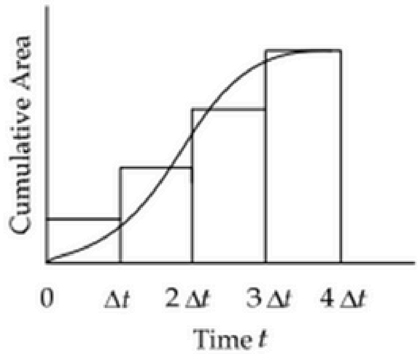


Figure 5.4 Time Area Curve

STEP 3

Determine the translated inflow hydrograph ordinates qi for any selected design hyetograph as Figure 5.3

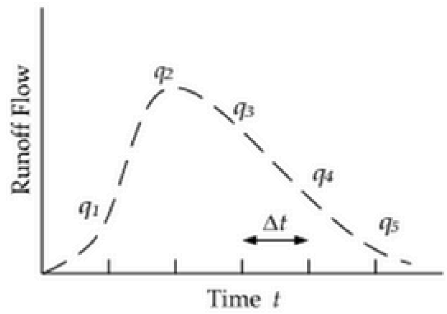


Figure 5.5 Runoff Hydrograph

STEP 4

Apply each block of storm (after deducting losses) as in Figure 5.6, the runoff from each sub-area reaches the outflow at lagged intervals defined by the time-area histogram.

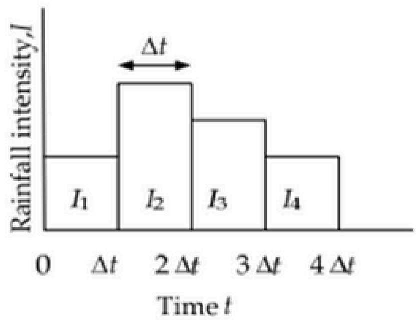


Figure 5.6 Time Area Curve

TIME-AREA HYDROGRAPH METHOD

The simultaneous arrival of the runoff from areas A1, A2,... for storm I1, I2,... should be determined by properly lagging and adding contributions or generally expressed as:

$$q_j = I_j \,.A_1 + I_{j-1}\,.A_2 + \ldots.. + I_1\,.A_j \qquad (27)$$

where,

q_j = Flow hydrograph ordinates (m³/s);
I_j = Rainfall excess hyetograph ordinates (m/s);
A_j = Time-area histogram ordinates (m²); and
j = Number of isochrone contributing to the outlet.

As an example for j = 3, the runoff from storms I1 on A3, I2 on A2 and I3 on A1 arrive at the outlet simultaneously, and q3 is the total flow. The inflow hydrograph (Figure 5.5) at the outlet can be obtained using Equation 27.

RAINFALL EXCESS

To calculate the rainfall excess (RE), total Rainfall must be deducted by losses, initial or continuous, which will result in the surface runoff hydrograph. The rainfall losses can be assumed constant (for simplicity) or decaying (to be more practical), as shown in Figure 5.7. The parameter values are given in Table 5.9.

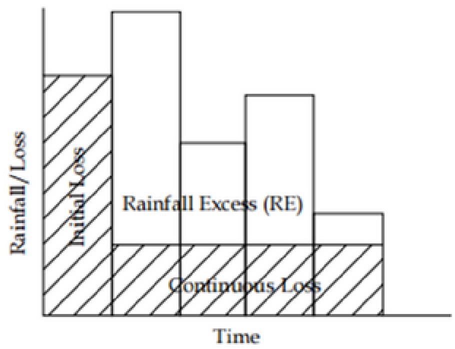


Figure 5.7 Initial and continuous Loss Concept for Runoff Estimation

Table 5.9 Recommended Loss Values

Catchment Condition	Initial Loss (mm)	Continuous Loss (mm/hr)
Impervious	1.5	0
Pervious	10	(i) Sandy Soil: 10 - 25 mm/hr (ii) Loam Soil: 3 - 10 mm/hr (iii) Clay Soil: 0.5 - 3 mm/hr

EXAMPLE 5.3

Using the Time-Area Hydrograph Method calculate a 20 year ARI runoff hydrograph from a 97 hectare mixed urban area located in Wangsa Maju, Kuala Lumpur. The study area is show in Figure 5.8.

Solution

STEP 1: Calculate Total Rainfall

Based on rainfall data of 20 year ARI and 30 minutes duration at station Ibu Pejabat JPS, Kuala Lumpur in Table 5.8, calculate rainfall intensity; i using equation 24

$$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}}$$ 24

Study location = Wangsa Maju, Kuala Lumpur
Rainfall Station = Ibu Pejabat JPS, Kuala Lumpur
ARI = 20 years

From Appendix A-1

CONSTANTS	VALUE
λ	61.976
K	0.145
Θ	0.122
η	0.818

(Note: Take the major system for ARI - T)
tc = 30 minutes

Storm Duration; d = (tc / 60) hour
= 30/60
= 0.50 hr

Thus, intensity is equal to

$$i = \frac{(61.976)(20)^{0.145}}{(0.500 + 0.122)^{0.818}}$$

$$i = \frac{95.691}{0.678}$$

i = 141.137 mm/hr

Intensity; i = 141.137 mm/hr

Therefore;

Total Rainfall = 141.137 mm/hr x (30/60) hr
= 70.569 mm

TABLE A-1 : Fitting constant for the IDF empirical equation for different location in Malaysia for High ARIs (2 - 100 years) Storm Duration (5 min - 72 hours)

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Kelantan	1	4614001	Brook	49.623	0.159	0.242	0.795
	2	4726001	Gunung Gagau	43.024	0.220	0.004	0.527
	3	4819027	Gua Musang	57.132	0.155	0.119	0.795
	4	4915001	Chabai	47.932	0.169	0.108	0.794
	5	4923001	Kg Aring	47.620	0.187	0.020	0.637
	6	5120025	Balai Polis Bertam	61.338	0.168	0.193	0.811
	7	5216001	Gob	41.783	0.175	0.122	0.720
	8	5320038	Dabong	51.442	0.189	0.077	0.710
	9	5322044	Kg Lalok	53.766	0.197	0.121	0.705
	10	5522047	JPS Kuala Krai	39.669	0.231	0.000	0.563
	11	5718033	Kg Jeli, Tanah Merah	72.173	0.196	0.360	0.703
	12	5719001	Kg Durian Daun Lawang	51.161	0.193	0.063	0.745
	13	5722057	JPS Machang	48.433	0.219	0.000	0.601
	14	5824079	Sg Rasau Pasir Putih	51.919	0.216	0.062	0.560
	15	6019004	Rumah Kastam Rantau Pjg	49.315	0.228	0.000	0.609
	16	6122064	Setor JPS Kota Bharu	60.988	0.214	0.148	0.616
Kuala Lumpur	1	3015001	Puchong Drop, K Lumpur	69.650	0.151	0.223	0.880
	2	3116003	Ibu Pejabat JPS	61.976	0.145	0.122	0.818
	3	3116004	Ibu Pejabat JPS1	64.689	0.149	0.174	0.837
	4	3116005	SK Taman Maluri	62.765	0.132	0.147	0.820
	5	3116006	Ladang Edinburgh	63.483	0.146	0.210	0.830
	6	3216001	Kg. Sungai Tua	64.203	0.152	0.250	0.844
	7	3216004	SK Jenis Keb. Kepong	73.602	0.164	0.330	0.874
	8	3217001	Ibu Bek. KM16, Gombak	66.328	0.144	0.230	0.859
	9	3217002	Emp. Genting Kelang	70.200	0.165	0.290	0.854
	10	3217003	Ibu Bek. KM11, Gombak	62.609	0.152	0.221	0.804
	11	3217004	Kg. Kuala Seleh, H. Klg	61.516	0.139	0.183	0.837
	12	3217005	Kg. Kerdas, Gombak	63.241	0.162	0.137	0.856
	13	3317001	Air Terjun Sg. Batu	72.992	0.162	0.171	0.871
	14	3317004	Genting Sempah	61.335	0.157	0.292	0.868

STEP 2: Calculate Rainfall Temporal Pattern - Appendix A-3: Normalised Design Rainfall Temporal Pattern

Based on rainfall data, rainfall temporal pattern is obtained from fraction for 30 minutes storm duration in Appendix A-3 as follows:

No. of Block	Storm Duration								
	15-min	30-min	60-min	180-min	6-hr	12-hr	24-hr	48-hr	72-hr
1	0.184	0.097	0.056	0.048	0.033	0.003	0.003	0.001	0.006
2	0.448	0.161	0.061	0.060	0.045	0.051	0.011	0.011	0.014
3	0.368	0.400	0.065	0.078	0.092	0.074	0.015	0.015	0.019
4		0.164	0.096	0.095	0.096	0.086	0.021	0.018	0.023
5		0.106	0.106	0.097	0.107	0.140	0.025	0.024	0.027
6		0.072	0.164	0.175	0.161	0.206	0.032	0.027	0.040
7			0.108	0.116	0.118	0.180	0.047	0.031	0.049
8			0.103	0.096	0.102	0.107	0.052	0.033	0.050
9			0.068	0.093	0.096	0.081	0.055	0.041	0.054
10			0.065	0.062	0.091	0.064	0.076	0.068	0.067
11			0.058	0.050	0.037	0.007	0.087	0.129	0.072
12			0.050	0.030	0.023	0.003	0.103	0.142	0.110
13							0.091	0.132	0.087
14							0.080	0.096	0.070
15							0.075	0.053	0.060
16							0.054	0.036	0.052
17							0.048	0.033	0.050
18							0.035	0.030	0.047
19							0.027	0.026	0.031
20							0.023	0.020	0.025
21							0.017	0.017	0.022
22							0.012	0.012	0.014
23							0.009	0.004	0.009
24							0.002	0.001	0.003

Rainfall Temporal Pattern = Fraction x Total Rainfall

0 - 5 : 0.097 x 70.569 = 6.845
5 - 10 : 0.161 x 70.569 = 11.362
10 - 15 : 0.400 x 70.569 = 28.228
15 - 20 : 0.164 x 70.569 = 11.573
20 - 25 : 0.106 x 70.569 = 7.480
25 -30 : 0.072 x 70.569 = 5.081

No.of Block	30-Min Storm Duration	Fraction	Total Rainfall (mm)	Rainfall Temporal Pattern (mm)
1	0 - 5	0.097	70.569	6.845
2	5 - 10	0.161	70.569	11.362
3	10 - 15	0.400	70.569	28.228
4	15 - 20	0.164	70.569	11.573
5	20 - 25	0.106	70.569	7.480
6	25 - 30	0.072	70.569	5.081

STEP 3: Assume The Losses

Using Table 5.9 to assume the losses, in decay form, as follows:
Given Initial Loss (mm):

30-Min Storm Duration	Initial Losses (mm)
0 - 5	3.5
5 - 10	3.0
10 - 15	2.5
15 - 20	2.0
20 - 25	1.5
25 - 30	1.0

STEP 4: Calculate Rainfall Excess For 20 Years ARI Design Rainfall

Rainfall Excess = Rainfall Temporal Pattern - Losses

30-Min Storm Duration	Time (min)	Rainfall Temporal Pattern (mm)	Initial Losses (mm)	Rainfall Excess (mm)
0 - 5	5	6.845	3.5	3.345
5 - 10	10	11.362	3.0	8.362
10 - 15	15	28.228	2.5	25.728
15 - 20	20	11.573	2.0	9.573
20 - 25	25	7.480	1.5	5.980
25 - 30	30	5.081	1.0	4.081

STEP 5: Estimate Area Between Isochrones Using AutoCAD

Given Areas between the Isochrones:

ID	30-Min Storm Duration	Area (m^2)
A_1	0 - 5	44 449
A_2	5 - 10	49 304
A_3	10 - 15	229 404
A_4	15 - 20	213 852
A_5	20 - 25	160 342
A_6	25 - 30	45 306

STEP 4: Calculate Rainfall Excess For 20 Years ARI Design Rainfall

Rainfall Excess = Rainfall Temporal Pattern - Losses

30-Min Storm Duration	Time (min)	Rainfall Temporal Pattern (mm)	Initial Losses (mm)	Rainfall Excess (mm)
0 - 5	5	6.845	3.5	3.345
5 - 10	10	11.362	3.0	8.362
10 - 15	15	28.228	2.5	25.728
15 - 20	20	11.573	2.0	9.573
20 - 25	25	7.480	1.5	5.980
25 - 30	30	5.081	1.0	4.081

STEP 5: Estimate Area Between Isochrones Using AutoCAD

Given Areas between the Isochrones:

ID	30-Min Storm Duration	Area (m^2)
A_1	0 - 5	44 449
A_2	5 - 10	49 304
A_3	10 - 15	229 404
A_4	15 - 20	213 852
A_5	20 - 25	160 342
A_6	25 - 30	45 306

STEP 6: Calculate Hydrograph Ordinate

$$\text{Hydrograph Formula} = \frac{(Area \times Rainfall\ Excess)}{(Time\ Interval \times 60)}\ \text{m}^3/\text{s}$$

$$= \frac{(44449 \times 0.003345)\ m^3}{(5 \times 60)\ s}$$

$$= \frac{148.682}{300}$$

= **0.496 m³/s**

List of answer in table 5.10.

STEP 7: Identify The Peak Discharge

From the Table 5.10: Time-Area Hydrograph Method, the peak discharge is 32.820 m³/s

Table 5.10

Time (min)	Area (m^2)	Rainfall Excess (mm)						Hydrograph (m^3/s)
		3.345	8.362	25.728	9.573	5.980	4.081	
		0.003345	0.008362	0.025728	0.009573	0.00598	0.004081	
0	0	0						0
5	44 449	0.496	0					0.496
10	79 304	0.884	1.239	0				2.123
15	229 404	2.558	2.210	3.812	0			8.580
20	213 852	2.384	6.394	6.801	1.418	0		16.998
25	160 342	1.788	5.961	19.674	2.531	0.886	0	30.839
30	45 306	0.505	4.469	18.340	7.320	1.581	0.605	**32.820**
35			1.263	13.751	6.824	4.573	1.079	27.489
40				3.885	5.117	4.263	3.121	16.385
45					1.446	3.196	2.909	7.551
50						0.903	2.181	3.084
55							0.616	0.616

EXAMPLE 5.4

A semi-detached houses will be developed at Taman Cempaka, Ipoh. The area for each isochrones as tabulated in table below. By assuming that loss of the catchment is 2.0mm and time of concentration, tc is 30 minutes and ARI rainfall is 5 years, estimate the peak discharge by using rainfall data from Politeknik Ungku Omar rainfall station. Given total rainfall is 112.63 mm

ISOCHRONES	AREA (m^2)
0 - 5	0.0562
5 - 10	0.0924
10 - 15	0.3292
15 - 20	0.2233
20 - 25	0.1694
> 25	0.0456

Solution

Total rainfall = 112.63 mm

Rainfall temporal pattern (refer Appendix A-3)
0 - 5 : 0.158 x 112.63 = 17.80mm
5 - 10 : 0.161 x 112.63 = 18.13mm
10 - 15 : 0.210 x 112.63 = 23.65mm
15 - 20 : 0.173 x 112.63 = 19.48mm
20 - 25 : 0.158 x 112.63 = 17.80mm
25 - 30 : 0.141 x 112.63 = 15.88mm

Losses = 2.0mm
Rainfall Excess
0 - 5 : 17.80 - 2 =15.80mm
5 - 10 : 18.13 - 2 = 16.13mm
10 - 15 : 23.65 - 2 = 21.65mm
15 - 20 : 19.48 - 2 = 17.48mm
20 - 25 : 17.80 - 2 =15.80mm
25 - 30 : 15.88 - 2 = 13.88mm

Hydrograph (m^3/s)

$$= \frac{Area\ (m^2)\ x\ Rainfall\ Excess\ (m)}{Time\ (s)}$$

$$= \frac{(0.0562\ x 1000^2)\ x\ (15.80/1000)}{(5x60)}$$

= 2.96 m^3/s

Table 5.10

Time (min)	Area (km²)	Rainfall Excess (mm)						Hydrograph (m³/s)
		3.345	8.362	25.728	9.573	5.980	4.081	
		0.003345	0.008362	0.025728	0.009573	0.00598	0.004081	
0	0	0						0
5	0.0562	2.96	0					2.96
10	0.0924	4.87	3.02	0				7.89
15	0.3292	17.34	4.97	4.06	0			26.37
20	0.2233	11.76	17.70	6.67	3.33	0		39.46
25	0.1694	8.92	12.01	23.76	5.38	2.96	0	53.03
30	0.0456	2.40	9.11	16.11	19.18	4.87	2.6	54.27
35			2.45	12.23	13.01	17.34	4.28	49.31
40				3.29	9.87	11.76	15.23	40.15
45					2.66	8.92	10.33	21.91
50						2.40	7.84	10.24
55							2.11	2.11

TUTORIAL

1 A bungalow houses will be developed at Taman Maluri, Kuala Lumpur. The area for each isochrones as tabulated in Table B4, estimate the peak discharge of 20 years ARI rainfall for that catchment with assuming losses for that catchment is 2.5 mm and time of concentration, tc is 30 minutes.

Isochrones	Area (m^2)	Time (min)	Total rainfall (mm)
0 - 5	44 449	5	7.73
5 - 10	49 304	10	12.83
10 - 15	229 404	15	31.87
15 - 20	213 852	20	13.07
20 - 25	160 342	25	8.45
25 - 30	45 306	30	5.74

2 Table below shows the data for a catchment in Kuala Selangor, Selangor. Calculate peak discharge by using Time Area Hydrograph method for the catchment.

Area (m^2)	Time (min)	Rainfall Excess (mm)
0	0	0
67307.14	5	7.73
120086.51	10	12.83
347376.24	15	31.87
323826.54	20	13.07
242798.73	25	8.45
68604.84	30	5.74

STUDENT AND EDUCATOR FEEDBACK

Completing this publication has been a significant challenge for the authors, who have dedicated considerable effort to making the book interactive, informative, and beneficial for both students and educators.

We would greatly appreciate it if you could take a few moments to provide your feedback.

Your input would be a valuable acknowledgment of their hard work.

Thank you for your time and support.

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APPENDIX

APPENDIX A-1

TABLE A-1 : Fitting constant for the IDF empirical equation for different location in Malaysia for High ARIs (2 - 100 years) Storm Duration (5 min - 72 hours)

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Johor	1	1437116	Stor JPS Johor Bahru	59.972	0.163	0.121	0.793
	2	1534002	Pusat Kem. Pekan Nenas	54.265	0.179	0.100	0.756
	3	1541139	Johor Silica	59.060	0.202	0.128	0.660
	4	1636001	Balai Polis Kg Seelong	50.115	0.191	0.099	0.763
	5	1737001	SM Bukit Besar	50.554	0.193	0.117	0.722
	6	1829002	Setor JPS Batu Pahat	64.099	0.174	0.201	0.826
	7	1834124	Ladang Ulu Remis	55.864	0.166	0.174	0.810
	8	1839196	Simpang Masai K. Sedili	61.562	0.191	0.103	0.701
	9	1931003	Emp. Semberong	60.568	0.163	0.159	0.821
	10	2025001	Pintu Kaw. Tg. Agas	80.936	0.187	0.258	0.890
	11	2033001	JPS Kluang	54.428	0.192	0.108	0.740
	12	2231001	Ladang Chan Wing	57.188	0.186	0.093	0.777
	13	2232001	Ladang Kekayaan	53.457	0.180	0.094	0.735
	14	2235163	Ibu Bekalan Kahang	52.177	0.186	0.055	0.652
	15	2237164	Jalan Kluang-Mersing	56.966	0.190	0.144	0.637
	16	2330009	Ladang Labis	45.808	0.222	0.012	0.713
	17	2528012	Rmh. Tapis Segamat	45.212	0.224	0.039	0.711
	18	2534160	Kg Peta Hulu Sg Endau	59.500	0.185	0.129	0.623
	19	2636170	Setor JPS Endau	62.040	0.215	0.103	0.592
Kedah	1	5507076	Bt. 27, Jalan Baling	52.398	0.172	0.104	0.788
	2	5704055	Kedah Peak	81.579	0.200	0.437	0.719
	3	5806066	Klinik Jeniang	59.786	0.165	0.203	0.791
	4	5808001	Bt. 61, Jalang Baling	47.496	0.183	0.079	0.752
	5	6103047	Setor JPS Alor Setar	64.832	0.168	0.346	0.800
	6	6108001	Kompleks Rumah Muda	52.341	0.173	0.120	0.792
	7	6206035	Kuala Nerang	54.849	0.174	0.250	0.810
	8	6107032	AmpangPadu	66.103	0.177	0.284	0.842
	9	6306031	Padang Senai	60.331	0.193	0.249	0.829

Source : Department of Irrigation and Drainage

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TABLE A-1 : Fitting constant for the IDF empirical equation for different location in Malaysia for High ARIs (2 - 100 years) Storm Duration (5 min - 72 hours)

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Kelantan	1	4614001	Brook	49.623	0.159	0.242	0.795
	2	4726001	Gunung Gagau	43.024	0.220	0.004	0.527
	3	4819027	Gua Musang	57.132	0.155	0.119	0.795
	4	4915001	Chabai	47.932	0.169	0.108	0.794
	5	4923001	Kg Aring	47.620	0.187	0.020	0.637
	6	5120025	Balai Polis Bertam	61.338	0.168	0.193	0.811
	7	5216001	Gob	41.783	0.175	0.122	0.720
	8	5320038	Dabong	51.442	0.189	0.077	0.710
	9	5322044	Kg Lalok	53.766	0.197	0.121	0.705
	10	5522047	JPS Kuala Krai	39.669	0.231	0.000	0.563
	11	5718033	Kg Jeli, Tanah Merah	72.173	0.196	0.360	0.703
	12	5719001	Kg Durian Daun Lawang	51.161	0.193	0.063	0.745
	13	5722057	JPS Machang	48.433	0.219	0.000	0.601
	14	5824079	Sg Rasau Pasir Putih	51.919	0.216	0.062	0.560
	15	6019004	Rumah Kastam Rantau Pjg	49.315	0.228	0.000	0.609
	16	6122064	Setor JPS Kota Bharu	60.988	0.214	0.148	0.616
Kuala Lumpur	1	3015001	Puchong Drop, K Lumpur	69.650	0.151	0.223	0.880
	2	3116003	Ibu Pejabat JPS	61.976	0.145	0.122	0.818
	3	3116004	Ibu Pejabat JPS1	64.689	0.149	0.174	0.837
	4	3116005	SK Taman Maluri	62.765	0.132	0.147	0.820
	5	3116006	Ladang Edinburgh	63.483	0.146	0.210	0.830
	6	3216001	Kg. Sungai Tua	64.203	0.152	0.250	0.844
	7	3216004	SK Jenis Keb. Kepong	73.602	0.164	0.330	0.874
	8	3217001	Ibu Bek. KM16, Gombak	66.328	0.144	0.230	0.859
	9	3217002	Emp. Genting Kelang	70.200	0.165	0.290	0.854
	10	3217003	Ibu Bek. KM11, Gombak	62.609	0.152	0.221	0.804
	11	3217004	Kg. Kuala Seleh, H. Klg	61.516	0.139	0.183	0.837
	12	3217005	Kg. Kerdas, Gombak	63.241	0.162	0.137	0.856
	13	3317001	Air Terjun Sg. Batu	72.992	0.162	0.171	0.871
	14	3317004	Genting Sempah	61.335	0.157	0.292	0.868

Source : Department of Irrigation and Drainage

TABLE A-1 : Fitting constant for the IDF empirical equation for different location in Malaysia for High ARIs (2 - 100 years) Storm Duration (5 min - 72 hours)

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Malacca	1	2222001	Bukit Sebukor	95.823	0.169	0.660	0.947
	2	2224038	Chin Chin Tepi Jalan	54.241	0.161	0.114	0.846
	3	2321006	Ladang Lendu	72.163	0.184	0.376	0.900
Negeri Sembilan	1	2719001	Setor JPS Sikamat	52.823	0.167	0.159	0.811
	2	2722202	Kg Sawah Lebar K Pilah	44.811	0.181	0.137	0.811
	3	2723002	Sungai Kepis	54.400	0.176	0.134	0.842
	4	2725083	Ladang New Rompin	57.616	0.191	0.224	0.817
	5	2920012	Petaling K Kelawang	50.749	0.173	0.235	0.854
Pahang	1	2630001	Sungai Pukim	46.577	0.232	0.169	0.687
	2	2634193	Sungai Anak Endau	66.179	0.182	0.081	0.589
	3	2828173	Kg Gambir	47.701	0.182	0.096	0.715
	4	3026156	Pos Iskandar	47.452	0.184	0.071	0.780
	5	3121143	Simpang Pelangai	57.109	0.165	0.190	0.867
	6	3134165	Dispensari Nenasi	61.697	0.152	0.120	0.593
	7	3231163	Kg Unchang	55.568	0.179	0.096	0.649
	8	3424081	JPS Temerloh	73.141	0.173	0.577	0.896
	9	3533102	Rumah Pam Pahang Tua	58.483	0.212	0.197	0.586
	10	3628001	Pintu Kaw. Pulau Kertam	50.024	0.211	0.089	0.716
	11	3818054	Setor JPS Raub	53.115	0.168	0.191	0.833
	12	3924072	Rmh Pam Paya Kangsar	62.301	0.167	0.363	0.868
	13	3930012	Sungai Lembing PCC Mill	45.999	0.210	0.074	0.590
	14	4023001	Kg Sungai Yap	65.914	0.195	0.252	0.817
	15	4127001	Hulu Tekai Kwsn."B"	59.861	0.226	0.213	0.762
	16	4219001	Bukit Bentong	73.676	0.165	0.384	0.879
	17	4223115	Kg Merting	52.731	0.184	0.096	0.805
	18	4513033	Gunung Brinchang	42.004	0.164	0.046	0.802
Penang	1	5204048	Sg Simpang Ampat	62.089	0.220	0.402	0.785
	2	5302001	Tangki Air Besar Sg Pinang	67.949	0.181	0.299	0.736
	3	5302003	Kolam Tkgn Air Hitam	52.459	0.191	0.106	0.729
	4	5303001	Rmh Kebajikan P Pinang	57.326	0.203	0.325	0.791
	5	5303053	Komplek Prai	52.771	0.203	0.095	0.717
	6	5402001	Klinik Bkt Bendera P Pinang	64.504	0.196	0.149	0.723
	7	5402002	Kolam Bersih P Pinang	53.785	0.181	0.125	0.706
	8	5404043	Ibu Bekalan Sg Kulim	57.832	0.188	0.245	0.751
	9	5504035	Lahar Ikan Mati Kepala Batas	48.415	0.221	0.068	0.692

Source : Department of Irrigation and Drainage

(Continued)

TABLE A-1 : Fitting constant for the IDF empirical equation for different location in Malaysia for High ARIs (2 - 100 years) Storm Duration (5 min - 72 hours)

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Perak	1	4010001	JPS Teluk Intan	54.017	0.198	0.084	0.790
	2	4207048	JPS Setiawan	56.121	0.174	0.211	0.854
	3	4311001	Pejabat Daerah Kampar	69.926	0.148	0.149	0.813
	4	4409091	Rumah Pam Kubang Haji	52.343	0.164	0.177	0.840
	5	4511111	Politeknik Ungku Umar	70.238	0.164	0.288	0.872
	6	4807016	Bukit Larut Taiping	87.236	0.165	0.258	0.842
	7	4811075	Rancangan Belia Perlop	58.234	0.198	0.247	0.856
	8	5005003	Jln. Mtg. Buloh Bgn Serai	52.752	0.163	0.179	0.795
	9	5207001	Kolam Air JKR Selama	59.567	0.176	0.062	0.807
	10	5210069	Stesen Pem. Hutan Lawin	52.803	0.169	0.219	0.838
	11	5411066	Kuala Kenderong	85.943	0.223	0.248	0.909
	12	5710061	Dispensari Keroh	53.116	0.168	0.112	0.820
Perlis	1	6401002	Padang Katong, Kangar	57.645	0.179	0.254	0.826
Selangor	1	2815001	JPS Sungai Manggis	56.052	0.152	0.194	0.857
	2	2913001	Pusat Kwln. JPS T Gong	63.493	0.170	0.254	0.872
	3	2917001	Setor JPS Kajang	59.153	0.161	0.118	0.812
	4	3117070	JPS Ampang	65.809	0.148	0.156	0.837
	5	3118102	SK Sungai Lui	63.155	0.177	0.122	0.842
	6	3314001	Rumah Pam JPS P Setia	62.273	0.175	0.205	0.841
	7	3411017	Setor JPS Tj. Karang	68.290	0.175	0.243	0.894
	8	3416002	Kg Kalong Tengah	61.811	0.161	0.188	0.816
	9	3516022	Loji Air Kuala Kubu Baru	67.793	0.176	0.278	0.854
	10	3710006	Rmh Pam Bagan Terap	60.793	0.173	0.185	0.884
Terengganu	1	3933001	Hulu Jabor, Kemaman	103.519	0.228	0.756	0.707
	2	4131001	Kg, Ban Ho, Kemaman	65.158	0.164	0.092	0.660
	3	4234109	JPS Kemaman	55.899	0.201	0.000	0.580
	4	4332001	Jambatan Tebak, Kem.	61.703	0.185	0.088	0.637
	5	4529001	Rmh Pam Paya Kempian	53.693	0.194	0.000	0.607
	6	4529071	SK Pasir Raja	48.467	0.207	0.000	0.600
	7	4631001	Almuktafibillah Shah	66.029	0.199	0.165	0.629
	8	4734079	SM Sultan Omar, Dungun	51.935	0.213	0.020	0.587
	9	4832077	SK Jerangau	54.947	0.212	0.026	0.555
	10	4930038	Kg Menerong, Hulu Trg	60.436	0.204	0.063	0.588
	11	5029034	Kg Dura. Hulu Trg	60.510	0.220	0.087	0.617
	12	5128001	Sungai Gawi, Hulu Trg	48.101	0.215	0.027	0.566
	13	5226001	Sg Petualang, Hulu Trg	48.527	0.228	0.000	0.547
	14	5328044	Sungai Tong, Setiu	52.377	0.188	0.003	0.558
	15	5331048	Setor JPS K Terengganu	58.307	0.210	0.123	0.555
	16	5426001	Kg Seladang, Hulu Setiu	57.695	0.197	0.000	0.544
	17	5428001	Kg Bt. Hampar, Setiu	55.452	0.186	0.000	0.545
	18	5524002	SK Panchor, Setiu Klinik	53.430	0.206	0.000	0.524
	19	5725006	Kg Raja, Besut	52.521	0.225	0.041	0.560

Source : Department of Irrigation and Drainage

TABLE A-2: Fitting constant for the IDF empirical equation for different location in Malaysia for Low ARIs (0.5 - 12 months) Storm Duration (5 min - 72 hours)

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Johor	1	1437116	Stor JPS Johor Bahru	73.6792	0.2770	0.2927	0.8620
	2	1534002	Pusat Kem. Pekan Nenas	62.6514	0.3231	0.1557	0.8212
	3	1541139	Johor Silica	79.5355	0.3363	0.2947	0.8097
	4	1636001	Balai Polis Kg Seelong	61.2124	0.3373	0.2375	0.8427
	5	1737001	SM Bukit Besar	61.3513	0.3027	0.2029	0.8240
	6	1829002	Setor Daerah JPS Batu Pahat	62.1576	0.3055	0.1423	0.8253
	7	1834124	Ladang Ulu Remis	59.1713	0.2935	0.1847	0.8380
	8	1839196	Simpang Masai K. Sedili	71.7947	0.2683	0.1863	0.8071
	9	1931003	Emp. Semberong	66.8854	0.3549	0.2107	0.8384
	10	2025001	Pintu Kaw. Tg. Agas	77.7719	0.3102	0.2806	0.8789
	11	2231001	Ladang Chan Wing	66.1439	0.3236	0.1778	0.8489
	12	2232001	Ladang Kekayaan	66.7541	0.3076	0.2270	0.8381
	13	2235163	Ibu Bekalan Kahang	62.3394	0.2786	0.1626	0.7389
	14	2237164	Jalan Kluang-Mersing	73.2358	0.3431	0.2198	0.7733
	15	2330009	Ladang Labis	65.2220	0.3947	0.2353	0.8455
	16	2528012	Rmh. Tapis Segamat	63.6892	0.3817	0.2586	0.8711
	17	2534160	Kg Peta Hulu Sg Endau	69.9581	0.3499	0.1808	0.7064
	18	2636170	Setor JPS Endau	77.6302	0.3985	0.2497	0.6927
Kedah	1	5507076	Bt. 27, Jalan Baling	62.7610	0.2580	0.3040	0.8350
	2	5704055	Kedah Peak	58.5960	0.3390	0.0640	0.661
	3	5806066	Klinik Jeniang	67.1200	0.3820	0.2380	0.8230
	4	5808001	Bt. 61, Jalan Baling	56.3990	0.3880	0.2520	0.8030
	5	6103047	Setor JPS Alor Setar	67.6410	0.3340	0.2740	0.8280
	6	6108001	Kompleks Rumah Muda	58.4040	0.2780	0.2340	0.8290
	7	6206035	Kuala Nerang	62.9600	0.3080	0.3590	0.8590
	8	6207032	Ampang Padu	70.9970	0.2930	0.3820	0.8630
	9	6306031	Padang Sanai	63.6150	0.3130	0.3090	0.8520

Source : Department of Irrigation and Drainage

TABLE A-2: Fitting constant for the IDF empirical equation for different location in Malaysia for Low ARIs (0.5 - 12 months) Storm Duration (5 min - 72 hours)

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Kelantan	1	4614001	Brook	49.7311	0.3159	0.1978	0.7924
	2	4915001	Chabai	56.2957	0.2986	0.1965	0.8384
	3	4923001	Kg Aring	70.2651	0.3810	0.2416	0.8185
	4	5120025	Balai Polis Bertam	67.7195	0.3271	0.2430	0.8424
	5	5216001	Gob	47.4654	0.2829	0.1531	0.7850
	6	5320038	Dabong	67.7907	0.3777	0.2740	0.8115
	7	5322044	Kg Lalok	67.7660	0.3288	0.2367	0.8188
	8	5522047	JPS Kuala Krai	63.0690	0.4681	0.3096	0.7833
	9	5718033	Kg Jeli, Tanah Merah	73.8139	0.3878	0.1161	0.7600
	10	5719001	Kg Durian Daun Lawang	67.2398	0.3651	0.1822	0.7531
	11	5722057	JPS Machang	57.3756	0.3441	0.1742	0.7085
	12	5824079	Sg Rasau, Pasir Putih	68.5083	0.4079	0.2019	0.7003
	13	6019004	Rumah Kastam Rantau Pjg	65.3650	0.4433	0.1582	0.7527
Kuala Lumpur	1	3015001	Puchong Drop, K Lumpur	68.5873	0.3519	0.1697	0.8494
	2	3116004	Ibu Pejabat JPS	65.9923	0.2857	0.1604	0.8341
	3	3116005	SK Taman Maluri	74.4510	0.2663	0.3120	0.8608
	4	3116006	Ladang Edinburgh	64.5033	0.2751	0.1814	0.8329
	5	3216001	Kg. Sungai Tua	62.9398	0.2579	0.1989	0.8374
	6	3216004	SK Jenis Keb. Kepong	69.7878	0.2955	0.1672	0.8508
	7	3217001	Ibu Bek. KM16, Gombak	66.0685	0.2565	0.2293	0.8401
	8	3217002	Emp. Genting Kelang	66.2582	0.2624	0.2423	0.8446
	9	3217003	Ibu Bek. KM11, Gombak	73.9540	0.2984	0.3241	0.8238
	10	3217004	Kg. Kuala Seleh, H. Klang	64.3175	0.2340	0.1818	0.8645
	11	3217005	Kg. Kerdas, Gombak	68.8526	0.2979	0.2024	0.8820
	12	3317001	Air Terjun Sg. Batu	75.9351	0.2475	0.2664	0.8668
	13	3317004	Genting Sempah	55.3934	0.2822	0.1835	0.8345

Source : Department of Irrigation and Drainage

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TABLE A-2: Fitting constant for the IDF empirical equation for different location in Malaysia for Low ARIs (0.5 - 12 months) Storm Duration (5 min - 72 hours)

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Malacca	1	2222001	Bukit Sebukor	78.1482	0.2690	0.3677	0.8968
	2	2224038	Chin Chin Tepi Jalan	66.0589	0.3363	0.3301	0.8905
	3	2321006	Ladang Lendu	64.7588	0.2975	0.2896	0.8787
Negeri Sembilan	1	2719001	Setor JPS Sikamat	60.4227	0.2793	0.2694	0.8540
	2	2722202	Kg Sawah Lebar K Pilah	49.3232	0.2716	0.2164	0.8503
	3	2723002	Sungai Kepis	61.3339	0.2536	0.3291	0.8717
	4	2725083	Ladang New Rompin	65.0249	0.3575	0.3546	0.8750
	5	2920012	Petaling K Kelawang	51.7343	0.2919	0.2643	0.8630
Pahang	1	2630001	Sungai Pukim Sungai	63.9783	0.3906	0.2556	0.8717
	2	2634193	Anak Endau	79.4310	0.3639	0.1431	0.7051
	3	2828173	Kg Gambir	61.1933	0.3857	0.1878	0.8237
	4	3026156	Pos Iskandar	59.9903	0.3488	0.2262	0.8769
	5	3121143	Simpang Pelangai	64.9653	0.3229	0.3003	0.8995
	6	3134165	Dispensari Nenasi	88.6484	0.3830	0.4040	0.7614
	7	3231163	Kg Unchang	71.6472	0.3521	0.1805	0.7886
	8	3424081	JPS Temerloh	62.2075	0.3528	0.3505	0.8368
	9	3533102	Rumah Pam Pahang Tua	80.8887	0.3611	0.4800	0.7578
	10	3628001	Pintu Kaw. Pulau Kertam	63.5073	0.3830	0.2881	0.8202
	11	3818054	Setor JPS Raub	61.3432	0.3692	0.3929	0.8445
	12	3924072	Rmh Pam Paya Kangsar	58.3761	0.3334	0.2421	0.8430
	13	3930012	Sungai Lembing PCC Mill	77.0004	0.4530	0.5701	0.8125
	14	4023001	Kg Sungai Yap	77.1488	0.3725	0.3439	0.8810
	15	4127001	Hulu Tekai Kwsn."B"	60.2235	0.4650	0.1241	0.8020
	16	4219001	Bukit Bentong	67.6128	0.2706	0.2459	0.8656
	17	4223115	Kg Merting	62.7511	0.2843	0.3630	0.9024
	18	4513033	Gunung Brinchang	42.1757	0.2833	0.1468	0.7850
Penang	1	5204048	Sg Simpang Ampat	59.3122	0.3394	0.3350	0.8090
	2	5302001	Tangki Air Besar Sg Pinang	71.7482	0.2928	0.2934	0.7779
	3	5302003	Kolam Tkgn Air Hitam	56.1145	0.2975	0.1778	0.7626
	4	5303001	Rmh Kebajikan P Pinang	60.1084	0.3575	0.2745	0.8303
	5	5303053	Kompleks Prai P Pinang	49.4860	0.3314	0.0518	0.7116
	6	5402001	Klinik Bkt Bendera P Pinang	68.0999	0.3111	0.1904	0.7662
	7	5402002	Kolam Bersih P Pinang	62.7533	0.2688	0.2488	0.7757
	8	5504035	Lahar Ikan Mati Kepala Batas	60.8596	0.3369	0.2316	0.7981

Source : Department of Irrigation and Drainage

(Continued)

TABLE A-2: Fitting constant for the IDF empirical equation for different location in Malaysia for Low ARIs (0.5 - 12 months) Storm Duration (5 min - 72 hours)

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Perak	1	5005003	JPS Teluk Intan	65.1854	0.3681	0.2552	0.8458
	2	4010001	JPS Setiawan	56.2695	0.3434	0.2058	0.8465
	3	4207048	Pejabat Daerah Kampar	79.2706	0.1829	0.3048	0.8532
	4	4311001	Rumah Pam Kubang Haji	47.8316	0.3527	0.1038	0.8018
	5	4409091	Politeknik Ungku Umar	62.9315	0.3439	0.1703	0.8229
	6	4511111	Bukit Larut Taiping	83.3964	0.3189	0.1767	0.8166
	7	4807016	Rancangan Belia Perlop	57.4914	0.3199	0.2027	0.8696
	8	4811075	Jln. Mtg. Buloh Bgn Serai	63.2357	0.3176	0.3330	0.8462
	9	5207001	Kolam Air JKR Selama	67.0499	0.3164	0.2255	0.8080
	10	5210069	Stesen Pem. Hutan Lawin	53.7310	0.3372	0.2237	0.8347
	11	5411066	Kuala Kenderong	68.5357	0.4196	0.1558	0.8378
	12	5710061	Dispensari Keroh	59.2197	0.3265	0.1621	0.8522
Perlis	1	6401002	Padang Katong, Kangar	52.1510	0.3573	0.1584	0.7858
Selangor	1	2815001	JPS Sungai Manggis	57.3495	0.2758	0.1693	0.8672
	2	2913001	Pusat Kwln. JPS T Gong	65.3556	0.3279	0.3451	0.8634
	3	2917001	Setor JPS Kajang	62.9564	0.3293	0.1298	0.8273
	4	3117070	JPS Ampang	69.1727	0.2488	0.1918	0.8374
	5	3118102	SK Sungai Lui	68.4588	0.3035	0.2036	0.8726
	6	3314001	Rumah Pam JPS P Setia	65.1864	0.2816	0.2176	0.8704
	7	3411017	Setor JPS Tj. Karang	70.9914	0.2999	0.2929	0.9057
	8	3416002	Kg Kalong Tengah	59.9750	0.2444	0.1642	0.8072
	9	3516022	Loji Air Kuala Kubu Baru	66.8884	0.2798	0.3489	0.8334
	10	3710006	Rmh Pam Bagan Terap	62.2644	0.3168	0.2799	0.8665
Terengganu	1	3933001	Hulu Jabor, Kemaman	74.8046	0.2170	0.2527	0.7281
	2	4131001	Kg, Ban Ho, Kemaman	68.6659	0.3164	0.1157	0.6969
	3	4234109	JPS Kemaman Jambatan	75.8258	0.2385	0.3811	0.7303
	4	4332001	Tebak, Kem.	77.2826	0.3460	0.3036	0.7301
	5	4529001	Rmh Pam Paya Kempian	65.2791	0.3642	0.1477	0.6667
	6	4631001	Almuktafibillah Shah	81.8861	0.3400	0.2600	0.7459
	7	4734079	SM Sultan Omar, Dungun	66.4262	0.3288	0.2152	0.7015
	8	4832077	SK Jerangau	81.4981	0.3736	0.4226	0.7586
	9	4930038	Kg Menerong, Hulu Trg	80.9649	0.3782	0.2561	0.7158
	10	5029034	Kg Dura. Hulu Trg	62.7859	0.3495	0.1103	0.6638
	11	5128001	Sungai Gawi, Hulu Trg	59.3063	0.4001	0.1312	0.6796
	12	5226001	Sg Petualang, Hulu Trg	51.7862	0.2968	0.0704	0.6587
	13	5328044	Sungai Tong, Setiu	63.4136	0.3864	0.0995	0.6540
	14	5331048	Setor JPS K Terengganu	67.0267	0.2844	0.2633	0.6690
	15	5426001	Kg Seladang, Hulu Setiu	76.9088	0.4513	0.1636	0.6834
	16	5428001	Kg Bt. Hampar, Setiu	57.9456	0.2490	0.0380	0.6000
	17	5524002	SK Panchor, Setiu	75.1489	0.4147	0.2580	0.6760

Source : Department of Irrigation and Drainage

A-3

TABLE A-3: Normalised Design Rainfall Temporal Pattern for Region 1 Terengganu and Kelantan

No. of Block	Storm Duration								
	15-min	30-min	60-min	180-min	6-hr	12-hr	24-hr	48-hr	72-hr
1	0.316	0.133	0.060	0.060	0.059	0.070	0.019	0.027	0.021
2	0.368	0.193	0.062	0.061	0.067	0.073	0.022	0.028	0.029
3	0.316	0.211	0.084	0.071	0.071	0.083	0.027	0.029	0.030
4		0.202	0.087	0.080	0.082	0.084	0.036	0.033	0.033
5		0.161	0.097	0.110	0.119	0.097	0.042	0.037	0.037
6		0.100	0.120	0.132	0.130	0.106	0.044	0.040	0.038
7			0.115	0.120	0.123	0.099	0.048	0.046	0.042
8			0.091	0.100	0.086	0.086	0.049	0.048	0.048
9			0.087	0.078	0.073	0.084	0.050	0.049	0.053
10			0.082	0.069	0.069	0.083	0.056	0.054	0.055
11			0.061	0.060	0.063	0.070	0.058	0.058	0.058
12			0.054	0.059	0.057	0.064	0.068	0.065	0.067
13							0.058	0.060	0.059
14							0.057	0.055	0.056
15							0.050	0.053	0.053
16							0.050	0.048	0.052
17							0.048	0.046	0.047
18							0.046	0.044	0.041
19							0.043	0.038	0.038
20							0.039	0.034	0.036
21							0.028	0.030	0.033
22							0.025	0.029	0.030
23							0.022	0.028	0.022
24							0.016	0.019	0.020

Source : Department of Irrigation and Drainage

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TABLE A-3: Normalised Design Rainfall Temporal Pattern for Region 2 Johor, Negeri Sembilan, Melaka, Selangor and Pahang

No. of Block	Storm Duration								
	15-min	30-min	60-min	180-min	6-hr	12-hr	24-hr	48-hr	72-hr
1	0.255	0.124	0.053	0.053	0.044	0.045	0.022	0.027	0.016
2	0.376	0.130	0.059	0.061	0.081	0.048	0.024	0.028	0.023
3	0.370	0.365	0.063	0.063	0.083	0.064	0.029	0.029	0.027
4		0.152	0.087	0.080	0.090	0.106	0.031	0.033	0.033
5		0.126	0.103	0.128	0.106	0.124	0.032	0.037	0.036
6		0.103	0.153	0.151	0.115	0.146	0.035	0.040	0.043
7			0.110	0.129	0.114	0.127	0.039	0.046	0.047
8			0.088	0.097	0.090	0.116	0.042	0.048	0.049
9			0.069	0.079	0.085	0.081	0.050	0.049	0.049
10			0.060	0.062	0.081	0.056	0.054	0.054	0.051
11			0.057	0.054	0.074	0.046	0.065	0.058	0.067
12			0.046	0.042	0.037	0.041	0.093	0.065	0.079
13							0.083	0.060	0.068
14							0.057	0.055	0.057
15							0.052	0.053	0.050
16							0.047	0.048	0.049
17							0.040	0.046	0.048
18							0.039	0.044	0.043
19							0.033	0.038	0.038
20							0.031	0.034	0.035
21							0.029	0.030	0.030
22							0.028	0.029	0.024
23							0.024	0.028	0.022
24							0.020	0.019	0.016

Source : Department of Irrigation and Drainage

TABLE A-3: Normalised Design Rainfall Temporal Pattern for Region 3 Perak, Kedah, Pulau Pinang and Perlis

No. of Block	Storm Duration								
	15-min	30-min	60-min	180-min	6-hr	12-hr	24-hr	48-hr	72-hr
1	0.255	0.124	0.053	0.053	0.044	0.045	0.022	0.027	0.016
2	0.376	0.130	0.059	0.061	0.081	0.048	0.024	0.028	0.023
3	0.370	0.365	0.063	0.063	0.083	0.064	0.029	0.029	0.027
4		0.152	0.087	0.080	0.090	0.106	0.031	0.033	0.033
5		0.126	0.103	0.128	0.106	0.124	0.032	0.037	0.036
6		0.103	0.153	0.151	0.115	0.146	0.035	0.040	0.043
7			0.110	0.129	0.114	0.127	0.039	0.046	0.047
8			0.088	0.097	0.090	0.116	0.042	0.048	0.049
9			0.069	0.079	0.085	0.081	0.050	0.049	0.049
10			0.060	0.062	0.081	0.056	0.054	0.054	0.051
11			0.057	0.054	0.074	0.046	0.065	0.058	0.067
12			0.046	0.042	0.037	0.041	0.093	0.065	0.079
13							0.083	0.060	0.068
14							0.057	0.055	0.057
15							0.052	0.053	0.050
16							0.047	0.048	0.049
17							0.040	0.046	0.048
18							0.039	0.044	0.043
19							0.033	0.038	0.038
20							0.031	0.034	0.035
21							0.029	0.030	0.030
22							0.028	0.029	0.024
23							0.024	0.028	0.022
24							0.020	0.019	0.016

Source : Department of Irrigation and Drainage

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TABLE A-3: Normalised Design Rainfall Temporal Pattern for Region 4 Mountainous Area

No. of Block	Storm Duration								
	15-min	30-min	60-min	180-min	6-hr	12-hr	24-hr	48-hr	72-hr
1	0.146	0.117	0.028	0.019	0.019	0.041	0.000	0.002	0.005
2	0.677	0.130	0.052	0.019	0.040	0.052	0.002	0.007	0.006
3	0.177	0.374	0.064	0.055	0.045	0.056	0.007	0.018	0.011
4		0.152	0.073	0.098	0.060	0.059	0.009	0.024	0.014
5		0.121	0.106	0.164	0.082	0.120	0.023	0.027	0.018
6		0.107	0.280	0.197	0.390	0.253	0.026	0.033	0.027
7			0.119	0.169	0.171	0.157	0.027	0.037	0.028
8			0.079	0.132	0.062	0.065	0.040	0.043	0.035
9			0.066	0.095	0.054	0.058	0.049	0.053	0.056
10			0.058	0.027	0.041	0.052	0.055	0.062	0.065
11			0.042	0.019	0.020	0.048	0.112	0.080	0.116
12			0.028	0.006	0.016	0.038	0.227	0.204	0.171
13							0.142	0.081	0.127
14							0.060	0.066	0.096
15							0.050	0.057	0.060
16							0.048	0.047	0.039
17							0.034	0.037	0.034
18							0.027	0.036	0.028
19							0.026	0.031	0.023
20							0.023	0.026	0.016
21							0.008	0.018	0.011
22							0.007	0.007	0.009
23							0.001	0.003	0.005
24							0.000	0.000	0.000

Source : Department of Irrigation and Drainage

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TABLE A-3: Normalised Design Rainfall Temporal Pattern for Region 5 Urban Area (Kuala Lumpur)

No. of Block	Storm Duration								
	15-min	30-min	60-min	180-min	6-hr	12-hr	24-hr	48-hr	72-hr
1	0.184	0.097	0.056	0.048	0.033	0.003	0.003	0.001	0.006
2	0.448	0.161	0.061	0.060	0.045	0.051	0.011	0.011	0.014
3	0.368	0.400	0.065	0.078	0.092	0.074	0.015	0.015	0.019
4		0.164	0.096	0.095	0.096	0.086	0.021	0.018	0.023
5		0.106	0.106	0.097	0.107	0.140	0.025	0.024	0.027
6		0.072	0.164	0.175	0.161	0.206	0.032	0.027	0.040
7			0.108	0.116	0.118	0.180	0.047	0.031	0.049
8			0.103	0.096	0.102	0.107	0.052	0.033	0.050
9			0.068	0.093	0.096	0.081	0.055	0.041	0.054
10			0.065	0.062	0.091	0.064	0.076	0.068	0.067
11			0.058	0.050	0.037	0.007	0.087	0.129	0.072
12			0.050	0.030	0.023	0.003	0.103	0.142	0.110
13							0.091	0.132	0.087
14							0.080	0.096	0.070
15							0.075	0.053	0.060
16							0.054	0.036	0.052
17							0.048	0.033	0.050
18							0.035	0.030	0.047
19							0.027	0.026	0.031
20							0.023	0.020	0.025
21							0.017	0.017	0.022
22							0.012	0.012	0.014
23							0.009	0.004	0.009
24							0.002	0.001	0.003

Source : Department of Irrigation and Drainage

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