ISBN : 978-602-96989-XX

MANUAL ON FLASHFLOOD MITIGATION MEASURES AND SYSTEM

DIRECTORATE OF RIVER AND COASTAL
DIRECTORATE-GENERAL OF WATER RESOURCES
MINISTRY OF PUBLIC WORKS
IN COOPERATION WITH:
JICA PROJECT ON INTEGRATED DISASTER MITIGATION MANAGEMENT FOR FLASHFLOOD

Foreword

This Manual on Flashflood Mitigation Measures and System is assembled to provide reference and practical guidance to field technicians and policy makers in the flashflood prone areas, for them to create infrastructures and systems to mitigate the impacts by knowing the characteristics of flashfloods and its causes.

This book is organized into four chapters:

I. Introduction

II. Flashflood

III. Action and Mitigation System of Flashflood

IV. Early Warning for Flashflood

The author humbly waits for criticism, suggestions and additional information to improve this book in the upcoming editions.

Semarang, March 2012

Authors,

Ir. HR Mulyanto Dip. HE, Team Leader

Ir. R. Nunus Ario Parikesit, MM, O&M Expert

Hariyono Utomo ST, MM, ISDM Expert

CONTENTS

List of Figures

List of Tables

I. INTRODUCTION

1.1 Flashflood

Flashflood is water stagnation due to outflow from streams caused by a sudden increase of discharge exceeding the stream capacity; it rapidly ran off lower areas, such as valleys and basins and usually carrying debris in its flow.

Flashflood is separated from flood by its rapid occurance (usually less than 6 hours); it wiped off fields on its path with massive flow rate and almost without adequate warning.

The height of flashflood waves ranges from 3-6 meters with debris, and is very dangerous to anything it ran over. Rain which causes flashflood may trigger landslides on slopes and cliffs and causes catastrophic flow of debris carried by the flashflood.

1.2 Types of Flashflood Etiology

Generally flashfloods are caused by one of these events below:

1.2.1 Heavy rain

- Heavy rain that moves slowly and falls into a not very large stream area with its runoff rapidly concentrated into the draining rivers.
- Heavy tropical rain that last quickly on areas saturated by previous rainfalls, or areas with small absorption capacity with its runoff rapidly concentrated into the draining rivers.

Due to the great discharge and flow rate, flashflood may carry rocks, mud (which it erode from cliffs or sedimentation deposit of the streambed) and other debris such as extracted tree trunks; and will wipe out anything on its path, destroy farm fields, bridges and houses, even causing casualties.

Flashflood may also occur due to the collapse of a natural dam which impounds the river flow, followed by spilling of the previously impounded water volume downstream. Natural dam is formed when stream flow is plugged by collapsed cliff materials along with tree trunks. Natural dam mostly occur on narrowing channels, although it doesn’t always happen on those locations.

In this event, flashflood may occur quickly within several minutes with no clear signs before it.

Flashflood is formed on the production channel and transportation channel which are not very large, approximately with a maximum area of 2000 hectares on a river system. The damage will be endured by people who lives in flashflood prone areas (along the base of sedimentation channel, below the apex point; and possibly also on the more upstream area along the transportation channel).

1.2.2 Failure / Collapse of Dams

Flashflood may also occur on the alluvial river bank areas due to collapse of dams. This may occur when there is, due to one cause or another, an elevation of stream level above the river banks.

This type of flashflood may cause major disaster but due to its incidental nature, it will not be discussed in this book.

1.3 Normative References

1.3.1 Laws

- Indonesian Law no.32 year 2009 on Protection and Management of Nature.
- Law no.7, year 2004 on Water Resources
- Law no.12, year 2008 on Revision of Law no.32 2004 on Regional Government
- Law no.24, year 2007 on Disaster Management

1.3.2 Government Regulation

- Government Regulation no.27, year 1999 on Analysis on Environmental Impact
- Government Regulation no.82, year 2001 on Management of Water Quality and Control of Water Pollution
- Government Regulation no.16, year 2004 on Stewardship of Land
- Government Regulation no.26, year 2008 on National Spatial Plan
- Government Regulation no.42, year 2008 on Water Resources Management
- Government Regulation no.37, year 2010 on Reservoir

1.3.3 Presidential Decree

- Presidential Decree no.12, year 2000 on Agency of Establishment and Control of Provision of Infrastructure and Facilities of Public Works.
- Presidential Decree no.62, year 2000 on Coordination of National Spatial Planning.
- Presidential Decree no.95, year 2000 on National Land Agency
- Presidential Decree no.23, year 2001 on Coordination Team of Water Resources Management.

1.3.4 Ministry’s Regulation

- Minister of Public Work Regulation no.603, year 2005 on General guidelines for the management control system of the development of infrastructure of public works.
- Minister of State Environmental Regulation no.11, year 2006 on Types of business plans and/or activities which must be supplemented with environmental impact analysis.

- Minister of State Environment Regulation no.12, year 2007 on Environment Management and Monitoring Document for business and/or activities without Environment Management Document.

1.3.5 Guidelines

- PdT-02-2005-A, Analysis of land bearing capacity for shallow foundation of water building.

1.3.6 General Stream Crib Planning Procedure, 1991, Department of Public Works

- SNI 03-2400-1991 on General Planning Procedure for River Crib, year 1991, Department of Public Works.
- SNI-03-2401-1991, SK SNI T-02-1990-F on General Planning Procedure for Reservoirs, 1991, Department of Public Works
- SNI 03-2829-1992 on Calculation method of Concrete Piles on River Cribs, 1992, Department of Public Works
- SNI 03-3441-1994 on Planning Procedure for River Bank Protection Technique of Stone Masonry, 1994, Department of Public Works
- PSN01 : 2007 on National Standardization Guidelines : Development of Indonesian National Standard.

1.3.7. ISO

- ☐ ISO 9001 : Quality Management Sistem
- ☐ ISO 14001 : Environment Management Sistem
- ☐ ISO 18001 : Safety Management Sistem

1.3.8. FEMA

FEMA 325 : Debris Management

1.4 Terms and Definition

- Rockslide or Debris slide is a type of debris mass movement with massive carrying capacity, coarse grains, and non cohesive; the materials consist from small to large grains (sand, gravel, cobbles and boulders).
- River Basin consists of a river, flood plain and the surrounding areas which are useful in enhancing flow of the river.
- Disaster threat is an event which may cause a disaster
- River buildings are buildings made to control, develop, protect and take advantage of the river.
- Emergency Disaster Relief is an effort to help fulfilling basic needs in an emergency situation
- Disaster is an event or a chain of events that threaten and disturbs the life and living of a community caused either by natural factors and/or human factors. It may cause casualties, environmental damage, material loss, and psychological impact.
- Natural Disaster is a disaster caused by an event or a chain of events caused by nature, such as earth quake, tsunami, volcano eruption, flood, drought, typhoon and landslide.
- Non natural disaster is a disaster caused by an event or a chain of non natural events, such as technological failure, modernization failure, epidemic, and plague.
- Sediment Disaster is an event or a chain of events caused by rockslide or debris slide that threaten and disturbs the life and living of a community caused by natural factors and/or non natural factors or human factors. It may cause casualties, environmental damage, material loss and psychological impact.
- Social disaster is a disaster caused by an event or a chain of events caused by human, including social conflict between groups or communities and terrors.
- Sediment Barrier is alluvial soil deposits in the river channel, consisting of sands and cobbles, with almost no vegetal covering. It is usually found in the curvature of a river channel.
- Gravel type debris or rock mass movement is a movement of debris mass containing many gravels.
- Mud flow type debris or rock mass movement is a movement of debris mass with low gravel content and dominated by sands and cobbles.
- River Management Agency is an authorized body in charge of managing rivers in accordance to the Government Regulation of Republic of Indonesia no.35, 1991 on Rivers.

- ISDM, Integrated Sediment Related Disaster Management is a concept of sediment disaster management that combines the role of community, regional programs and necessary disaster mitigation measures.
- Disaster prevention measures are chains of activities done as an effort to remove and/or reduce the threat of disaster.
- Preparedness is a chain of events done as an effort to anticipate disaster through organizing appropriate and useful measures.
- Disaster victim is a person or people who suffer or die from a disaster.
- International Institutes are organizations within the structure of United Nations or representing United Nations or other International Institutions and nongovernmental foreign institutions outside the United Nations.
- Business Institution is any legal entities that may take forms in state-owned company, regional state-owned company, union, or private company; established with the provisions of the legislation and continue its work and domicile within the Republic of Indonesia territory.
- Mitigation is a chain of effort to reduce the risk of disaster, either through physical development, increasing awareness or improving ability to face the threats of disaster.
- Minor repair works are small scale activities of building repairs to restore it to the planned capacity.This include minor damages, such as elevation of dam's surface, repairing leaks on a dam, installing rock shield for dam located near to a mining area, exchanging doors, etc that suffer from minor damages and failures.
- Maintenance is the activities and works done on available buildings to preserve and keep the river and building's functions in accordance to the planned level of service.
- River Building Maintenance is maintenance on river channels and river buildings.
- Periodic Maintenance is scheduled activities done from time to time and going in interrupted intervals with the goal to preserve/ maintain the functions of available infrastructures.
- Emergency maintenance is maintenance that needs to be done as soon as possible in order to prevent further damage. The work is important to protect the wholeness and strength (in big scale) of the building. Emergency maintenance may also include flood management activities such as installation of sand bags on dams before and during the flood to prevent overflow.
- Special Maintenance is (big scale) maintenance of buildings or parts of a building with performance score less than 70%, but still more than 50% of its plan.

- Corrective Maintenance is a more basic maintenance that needs to be done to restore its condition as it was when it was just built, such as building supporting walls or paired wings of the moving part of the reservoir or repairing cracks and slides, and correcting a job that has been failed several times over and over again or does not work as expected.
- Preventive Maintenance is activities done to optimally preserve the function of rivers and buildings. Preventive maintenance consist of:
- Routine Maintenance is an overall job done repeated annually, managed by schedule.
- Local Government is a governor, regent/mayor, or local authorities as the element of regional administration.
- Central Government, hereinafter called the Government, is the President of Republic of Indonesia, who holds the power to govern Republic of Indonesia as defined in the Constitution of Republic of Indonesia Year 1944.
- Recovery is a chain of events to restore the condition of the community and environment that were struck by a disaster by re-establishing the institutions, infrastructures and facilities by implementing rehabilitational efforts.
- In-stream Countermeasures are structural countermeasures of sediment disasters implemented inside the river channel.
- Non structural sediment disaster countermeasures are countermeasure efforts that do not involve building any structure (physical development).
- Structural Sediment Disaster Countermeasures are countermeasures efforts done by countering the movement or flow of land mass by building a structure (physical development).
- Off-stream Countermeasure is a structural countermeasure of sediment disaster implemented outside the river channel.
- Disaster prevention is a series of efforts to reduce or remove the risk of disaster, either by reducing the threat of disaster or the vulnerability of the threaten parties.
- Refugee is a person or a group of people that were forced to move out from their residences for an uncertain period of time as the impact of disaster.
- Disaster Countermeasures are chains of efforts involving the enforcement of potential disaster development policy, disaster preventing measures, emergency rescue and rehabilitation.
- Early warning is a series of effort to warn the community as soon as possible about the possibility of a disaster that may occur in a place by the authorized institution.

- Maintenance program is a systematically arranged schedule of events to manage the maintenance effort within a system.
- Disaster-prone is a condition or characteristic of geology, biology, hydrology, climatology, geography, social, culture, politic, economy and technology of an area for a certain period of time that hinder the ability to prevent, dampen the ability to achieve readiness; and reduce the ability to response the impact of a certain danger.
- Rehabilitation is an effort to repair the damage on river buildings and to restore the building's functions as it was before, without changing the system or the service level of the building, where as the building's function is less than 50%.
- Social Rehabilitation is the repair and restoration of all aspects of public services or communities in post disaster areas to an adequate level. The main goal is to normalize all aspects of government and community lives on post disaster areas.
- Reactivation is the effort to repair and to increase the function of a building, for example a crib does not function well to protect talud from erosion.
- Reconstruction is rebuilding all of the infrastructures and facilities, and institutionalization on post disaster areas, either on government or community level with the main goal to develop activities on economy, social and culture, upholding the law and order, and the rise of community role in all aspect of community living in post disaster areas.
- Risk of Disaster is the potential loss caused by disaster in an area, within a certain period of time. Be it death, wounds, sickness, threatened lives, lost of sense of security, evacuation, material damage or material loss, and disturbance of community activities.
- Everyone is individual persons, group of people, and/or corporation.
- Emergency Disaster Status is a condition stated by the government for a period of time based on the recommendation of a certain authorized institution to prevent disaster.
- River is:
    - Vessels or reservoir and the natural channeling of water with all of its content from DPS to lower ground and ends at sea, or
    - Places and vessels and drainage network from the spring to estuary bounded by the line of demarcation on its left and right.
- Emergency response is a series of activities carried out immediately at the time of disaster to deal with the negative impacts which include rescue and evacuation of casualties, property, fulfillment of basic needs, protection, management of refugees, rescue, and recovery of infrastructure and facilities.

II.FLASHFLOOD

2.1 The Technical Aspects of River

2.1.1 River System

A river system consists of a main river and tributaries. It serves as the drainage channels of a watershed, moving water downstream, and transports carried sediments.

A river channel has to meet certain hydrologic characteristics, perennial stream with discharge at least in most of the time in a year.

Robert E.Horton (1945) developed the basic concept of the Order of river and creeks, which later were modified by Strahler (1957).

a. One most upstream tributaries that doesn’t branch is determined as Order-1 river.

b. Two Order-1 rivers join together to form an Order-2 river.

c. Two Order-2 rivers join together to form an Order-3 river.

d. A river of Order-3 is not called an Order-4 when it is joined by an Order-1 or Order-2 river.

e. Increase in the Order-3 to Order-4 occurs when that stream is joined with another Order-3 river.

A river network with small amount of suppliers has a high probability to cause flood because the discharge is focused in one channel instead of spread out (like when the number supplier is high).

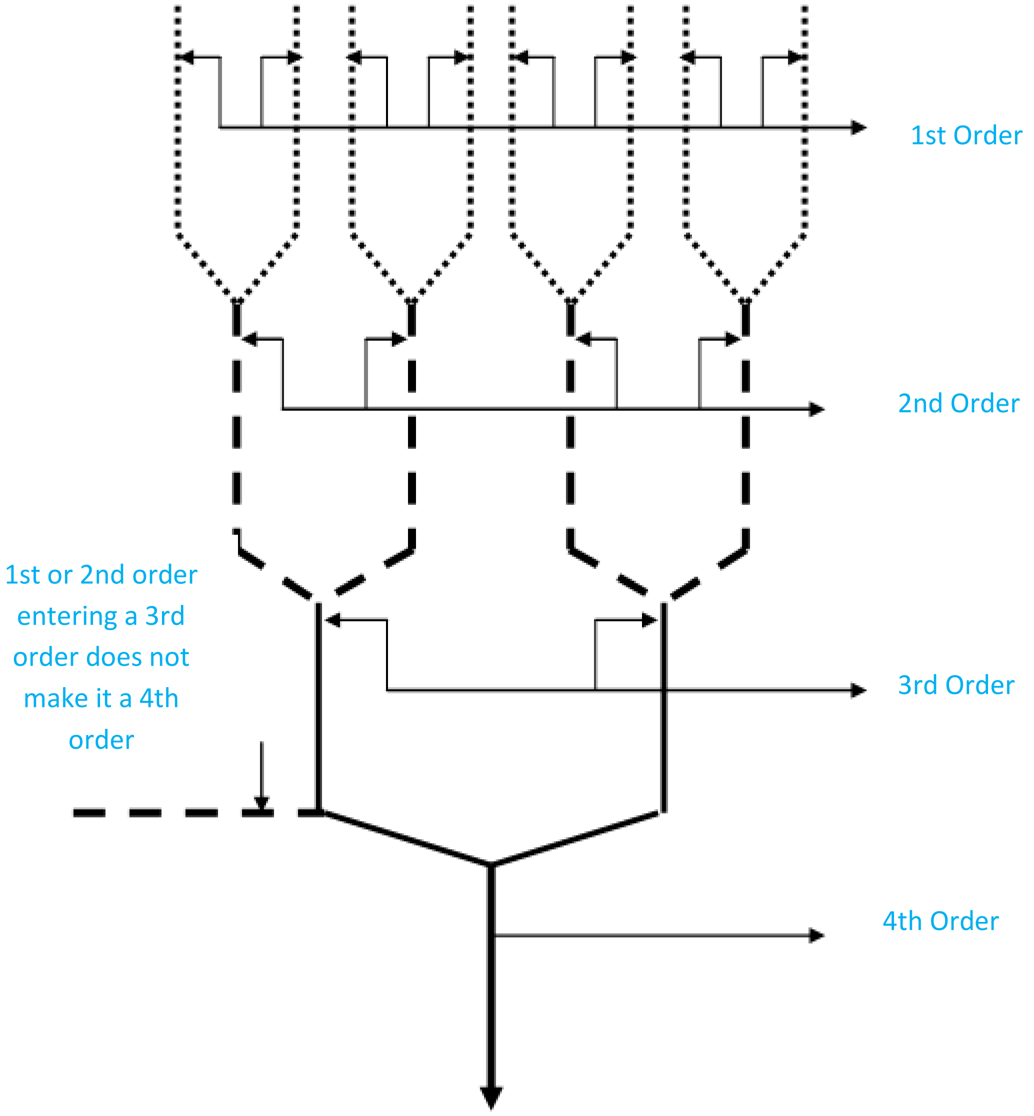


Figure 2.1. The Horton Stream Order Scheme

2.1.2 Classification of River Segments

A river from the upstream to its estuary in general may be divided into four segments, each with their own properties:

1. Upstream Segment:
    i. Torrential/rapid segment
    ii. Braided segment
2. Alluvial Segment
3. Tide influenced segment /Tidal reach

4. Estuary Segment

Each river segments has distinct properties.

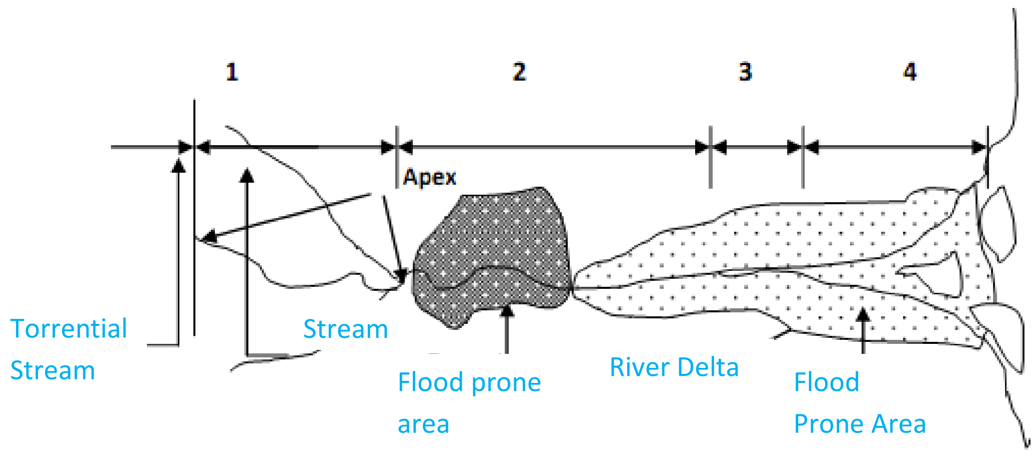


Figure 2.2. River Segments

2.1.3. The Properties of River segments

The properties of a river segment depend on where that segment flows and the slope of its bed. It is also related with the characteristics of sediment that it can carry. The table below shows the classification of river segments.

Table 2.1 Classification of River Segments

Classification	Upstream Segment	Downstream Segment		
		Alluvial Segment	Tidal Segment	Estuary Segment
Streambed materials	Boulder, Cobble	Cobble to Sand	Sand to Clay	Sand to Clay
Stream Pattern	I.rapids/torrential, II.Braided	Braided / Meander	Meander to Straight	Branched out
Stream direction	Downstream	Downstream	Two ways; downstream, and upstream on tides	Two ways; downstream, and upstream on tides

Sediment Load	Debris flow and Individual flow by the flow traction	Individual flow by flow traction	Traction and suspension	Suspension and traction
Depth of channel	Various from deep to shallow	Deep	Deep	Shallow
Streambed Slope	torrent >0.03 braided 0.01 –> 0.03	1/100 s/d 1/2000	≤1/2000	➔ 0 (very small)
The nature of flood	Torrential : Sudden increase of discharge Braid: Sudden increase of discharge and possibility of flash flood	Under apex : flash flood and flood on downstream	Flood and tidal flood	Flood and tidal flood
Nature of Sediment Movement	Torrential: Production area Braid : Transportation area	Sedimentation area	Sedimentation area	Sedimentation area

2.1.4. Floodplain

The cross sectional area of a channel is mainly determined by the dominant Q (Q1th or Q2th), which is the maximum discharge of the cross sectional area of a river. When heavier rain falls on the upstream, the cross sectional area will not be able to channel the whole discharge (>Qdom) therefore erosion occur to increase the area of the channel, and increases its flow capacity.

- In torrential stream, the erosion that occurs to increase the capacity of the channel does so by erroding the streambed deeper.
- In braided stream, the erosion to increase capacity of the channel occurs by erroding the river banks and widens the channel.
- In aluvial channel the erosion and sedimentation take turns on the stream bed and forming bends or meanders.

If erosion is no longer possible, that is when the depth of the stream bed had reached a hard layer or when the slope angle is flat enough, the balanced depth is then achieved. Water will flow out of the channel, especially on low river banks. In nature the chance for this outflow to happen is every 1-2 years when the bankful discharge has been passed.

The Floodplain is commonly located on the downstream of the apex point. Apex point is the location of change of streambed slope from steep to more flat, especially on the upper border of alluvial plain base, which causes a decrease of flow rate inside the channel. Here, the cross sectional area of the channel cannot increase quickly enough to adjust to the amount of discharge from the upstream of apex point.

Nature provides an area with low elevation on the river valley as a retention area (floodplain), which functions to contain those outflows. The width of inundated floodplain area depends on the frequency of flood.

Water entering floodplain will carry some sediment. Due to the trap efficiency effect of floodplain plus the reduced flow rate on its upper part, some of the sediment will be deposited on its bed while the water stagnates. With recurrent water stagnation in a long period, the plain will eventually form a naturally reclaimed alluvial plain. The reduction of water flow rate flowing out of the channel, which then drawn back inside will form sedimentation on both banks, creating ridges along the channel. Both ridges are called as natural levees. It may reach 5-10 meters high above the floodplain.

By forming natural levees on both banks, the capacity of the channel increases. If a flood outflows above it the natural leeve may collapse and causes flood outside.

2.2 Types of Flashflood by its causes.

2.2.1 Rainfall with rapid concentration

I.Hydrology aspect

Hydrology cycle: is the constant movement of humidity on earth that forms a circle. It starts from the ocean as an evaporation process (E = evaporation), then condenses and becomes rain (precipitation), and finally flowing through river back to the sea as discharge (R=runoff).

$$P - E = A_{P+at)} + R$$

Where:

P = Precipitation /rainfall.

A = accumulation of contemporary stagnated water in the watershed as:

Ap = Accumulation of surface water such as lake, swamp, etc; stagnation and those inside the river channel.

Aat = Accumulation of underground water that fill aquifers, be it phreatic aquifer or artesian aquifer. Aquifer: is a layer of soil with water content filling its pores. It is a reservoir of underground water.

a. Phreatic Aquifer: Underground water in it directly contacts the atmosphere and has equal pressure with the atmosphere at its surface.

b. Artesian Aquifer: Underground water in it is pressed between two impervious layers and has higher pressure than the atmosphere.

E = Total Evaporation of all watershed surface.

P-E = also called as the water availability of the watershed.

This process may be summarized in the following equation:

$$R = P – A$$

Where the value of A may be:

- Positive at the time of accumulation or when water reservoirs are filling, (R<P); and
- Negative (R>P) when effluency happens, which is the emptying of those reservoirs.

When a river basin has been saturated or with zero absorption capacity and reserve capacity, then most of the rainfall will become runoffs.

If heavy rainfall occurs on top of an Order-1 river basin, runoff will enter the channel rapidly and form a sudden hydrograph spike and causes flashflood downstream.

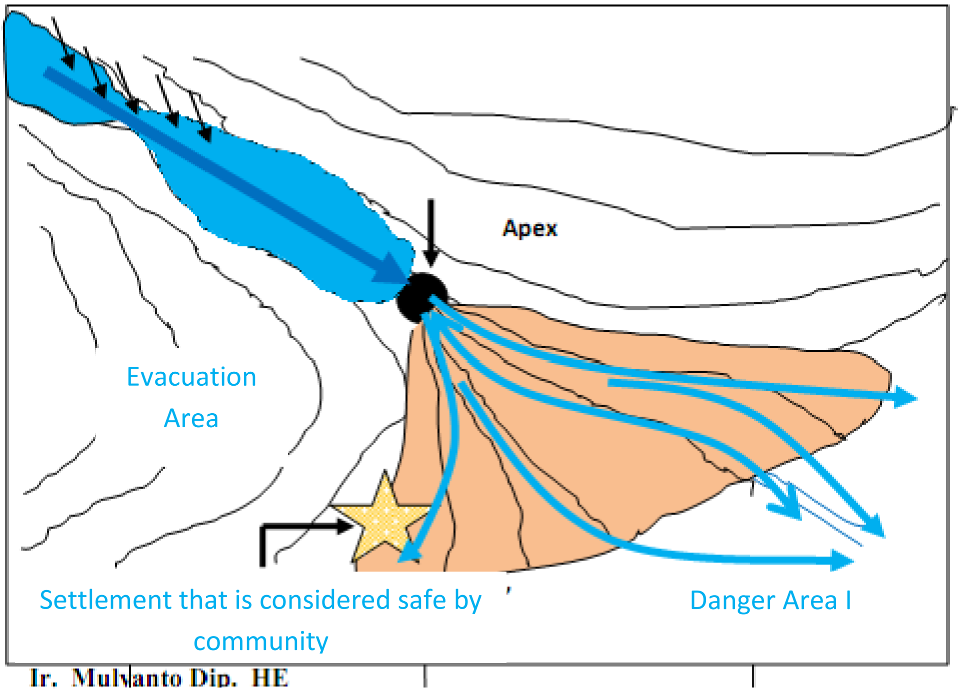


Figure 2.3. Flashflood prone area type 1

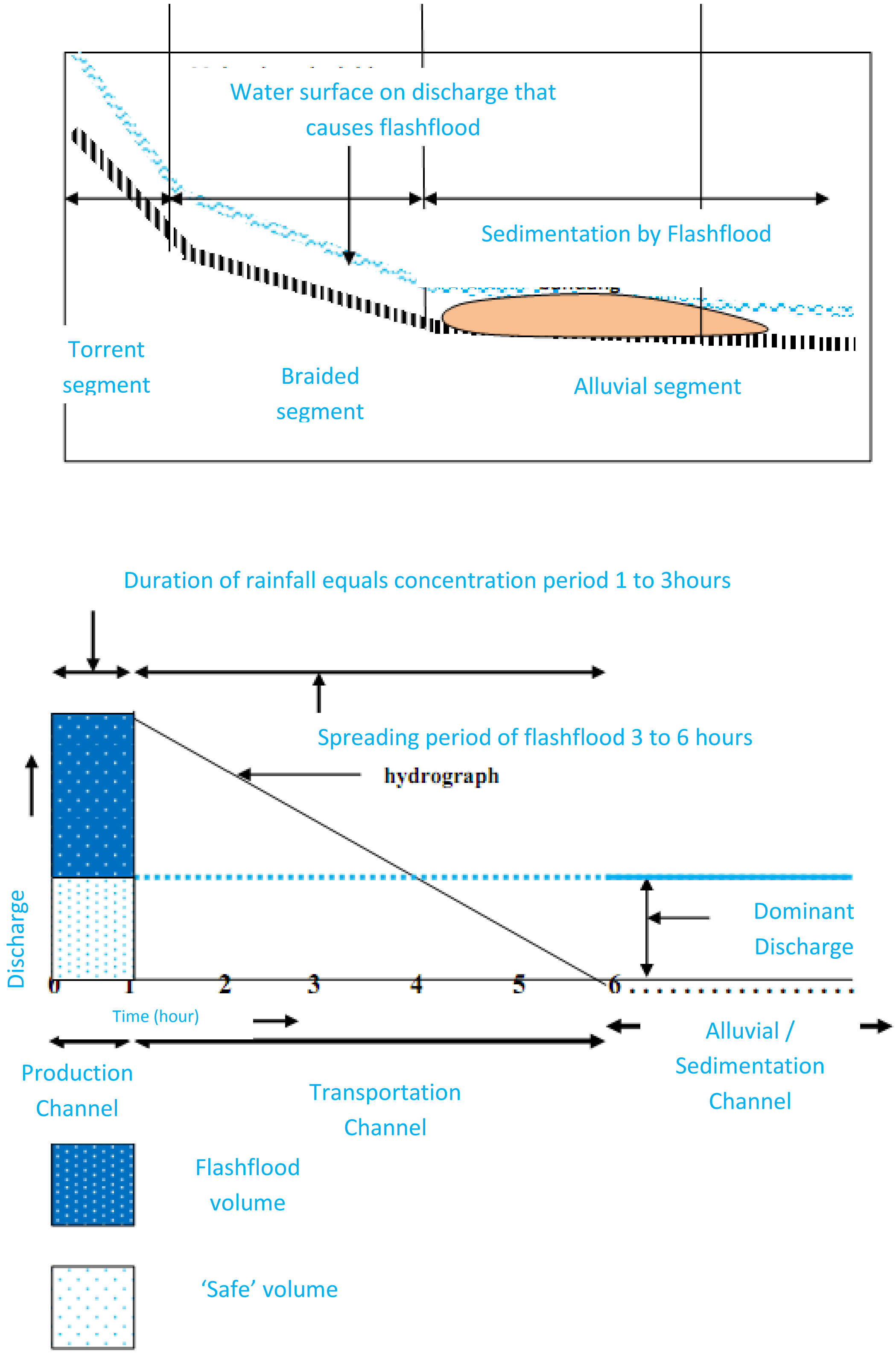


Figure 2.4 Sketch of Flashflood Formation

ii. Rational Method

a. Rational method is used to estimate peak discharge on extreme rain for a medium sized river basin (<100ha), where there is no significant flood storage (accumulation).

Assumption of Rational Method:

Runoff formed from rain with constant intensity is valued at maximum, when the duration (of rain) is equal to the concentration time. This assumption isn't very accurate when the watershed area grows larger, because the concentration period becomes very long and the intensity of rain is no longer constant, but varies on the whole area.

Peak discharge frequency is equal with frequency of rain intensity in a certain concentration period, and depends on:

- Rain frequency
- Maximum humidity conditions in the watershed
- Reaction from drainage system characteristics

On a small and mostly impervious area, the dominant factor is rain frequency. On a larger watershed, the characteristics are mainly influenced on rain frequency.

In reality the rainfall intensity is distributed within time and space. The assumption of evenly distributed rainfall is acceptable on smaller watershed.

Rainfall (C) that becomes runoff especially on impervious area varies by the intensity of rainfall and the prior humidity condition.

b. Concentration period

To calculate the timing of flood / concentration period, this equation is used:

$$t_p = CA^{0.22} re^{-0.35}$$

Where:

Tp = the timing of flood arrival (minute).

Re = effective rainfall intensity (mm/hour)

A = Catchment area (km2)

C: coefficient

Another equation that may be used is the Izzard Equation.

With Izzard equation, some topographic factors are considered as contributing factors: distance of stream surface, slope of the field, both forming a restriction coefficient for the runoff flow and the concentration period.

$$tc = \left(\frac{41L^{1/3}}{i^{2/3}} \right) \left(\frac{0.0007i + cr}{s^{1/3}} \right)$$

Where:

tc = concentration time

L= length of flow

I = intensity of rainfall

cr = coefficient of flow resistance

S = slope of the field.

c. Rational method equation

The rational equation estimates the peak discharge on extreme rainfalls on a certain location within the watershed.

- As a function of watershed area
- Runoff coefficient
- Average rainfall intensity with duration equals to the concentration period such as below:

$$Q = \frac{CIA}{360}$$

(Formula A)

Where:

Q = maximum runoff discharge (m3/s)

C = runoff coefficient like mentioned below

I = average rainfall intensity (mm/hour) like described below

A = drainage area (ha)

360 = conversion factor when using metric unit.

d. Rainfall intensity

Rainfall intensity (I) is the average rainfall (mm/hour) on certain duration of rainfall and with a chosen frequency.

The general shape of curve of intensity – duration – rainfall is described in figure 2.5 to figure 2.9. The value of rainfall intensity inclines to infinity. Due to the assumption that duration equals to concentration period, small areas with very small concentration period causes the intensity of rainfall becomes very high. To avoid it, the considered concentration period is a minimum of 10 minutes. Rainfall duration tends to incline to infinity and the planned rain tends to be very small. Area suitable for this curve usage is limited up to 100 hectares.

Rainfall intensity (mm) to duration of rainfall (minutes or hours) and frequency (year) on several locations in Indonesia, assembled by Flow Regimes from International Experimental and Network Data (FRIEND) on its publication in 2008 Rainfall Intensity and Duration Frequency (IDF) for Asia Pacific mentioned the IDF for several places in Indonesia:

Bandung, Bogor, Bali, Jakarta and Semarang, with their curves on the figures below and table 2.2.

Average Rain Intensity (year)	Depth (mm) – Duration (min/hr) – Frequency (years) for Indonesia									
	Bandung									
	2m	10m	15m	30m	45m	60m	120m	180m	360m	720m
2	13	17.8	23.4	44.4	43.4	49.8	57.9	60.4	67.6	73.5
5	16.3	21.3	27.8	65.8	48.8	56.7	67.7	72.3	82.3	88.7
10	18.5	23.6	30.7	79.9	52.4	61.4	74.3	80.2	92	98.8
20	20.5	25.8	33.5	93.5	55.8	65.8	80.5	87.8	101.3	108.5
50	23.2	28.6	37.1	111.1	60.3	71.6	88.7	97.6	113.3	121.1
	Bogor									
2	11.2	21.6	31.8	55	68.8	80.6	97.6	108.2	115.2	118.8
5	12.7	24.3	34.5	62.6	77.2	89.4	114.8	128.5	138.5	141.1
10	13.7	26	36.2	67.6	82.8	95.2	126.1	142	154	155.9
20	14.6	27.7	37.9	72.4	88.1	100.7	137	154.9	168.8	170
50	15.9	29.9	40.1	78.7	95	107.9	151.1	171.7	188.1	188.3
	Bali									
2	13.5	21.3	28.7	45.1	52.2	59.7	70.7		92.4	113
5	18.7	27.4	36.4	55.2	63.3	74.2	88.4		114.9	154.7
10	22.2	31.4	41.4	62	70.7	83.9	100.1		129.9	182.3
20	25.5	35.2	46.3	68.4	77.8	93.1	111.4		144.2	208.8
50	29.8	40.2	52.6	76.7	87	105.1	125.9		162.8	243.1
	Jakarta									
2	12.5	20.6	26.2	39.2	44.2	53.5	62.9	66	71.3	74.4
5	18	28.7	37	54.7	63.8	75.7	90.2	95.9	106.7	113
10	21.6	34.1	44.1	65	76.8	90.3	108.3	115.7	130.2	138.6
20	25.1	39.3	50.9	74.8	89.3	104.4	125.7	134.7	152.6	163.1
50	29.6	46	59.8	87.6	105.4	122.5	148.2	159.2	181.7	194.9
	Semarang									
2	16.4	24	32.1	51	61.8	74.4	101.7	106.6	108.8	109
5	20.9	29.3	36.3	59.9	74	90.9	124.4	133.3	136.2	136.5
10	23.9	32.8	39.1	65.7	82.1	101.8	139.5	151	154.4	154.7
20	26.8	36.2	41.8	71.3	89.8	112.3	153.9	167.9	171.8	172.2
50	30.5	40.6	45.2	78.6	99.9	125.9	172.6	189.8	194.4	194.9

Table 2.2 IDF of several locations in Indonesia

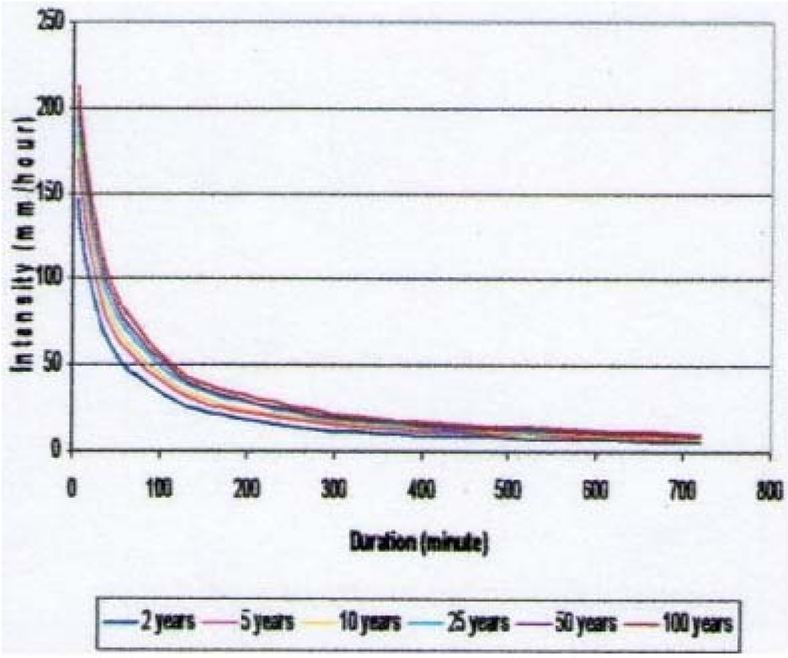


Figure 2.5. Typical Rainfall Intensity Duration Frequency Curve at Bandung Station

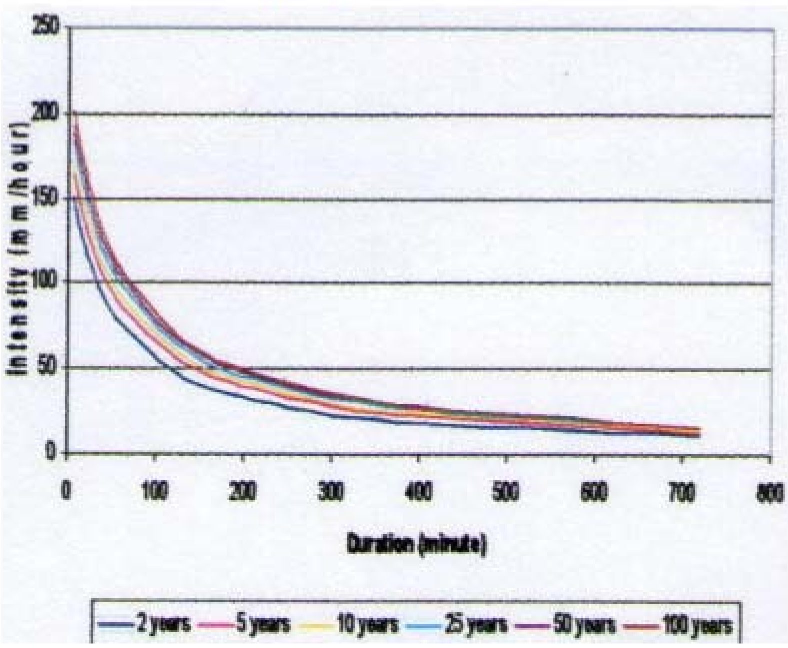


Figure 2.6. Typical Rainfall Intensity Duration Frequency Curve at Bogor Station

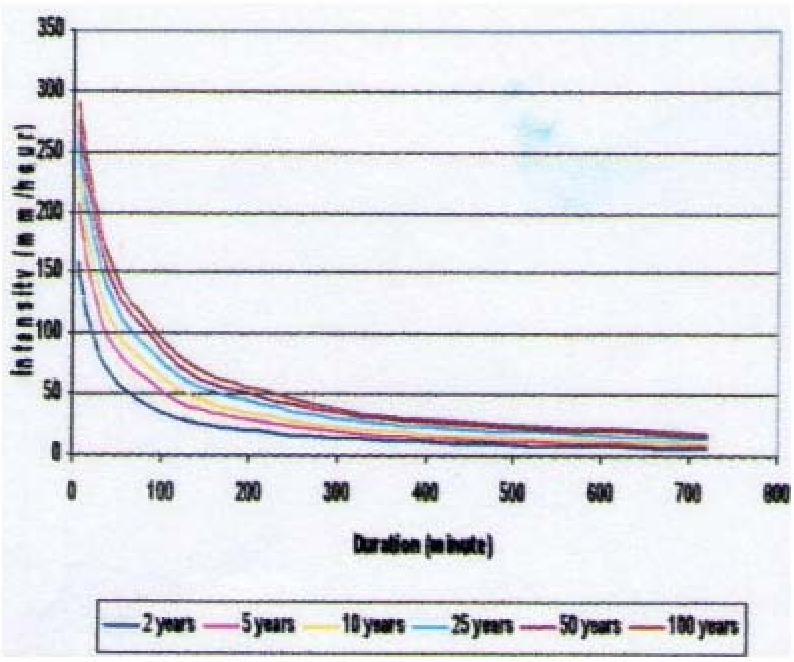


Figure 2.7. Typical Rainfall Intensity Duration Frequency Curve at Jakarta Station

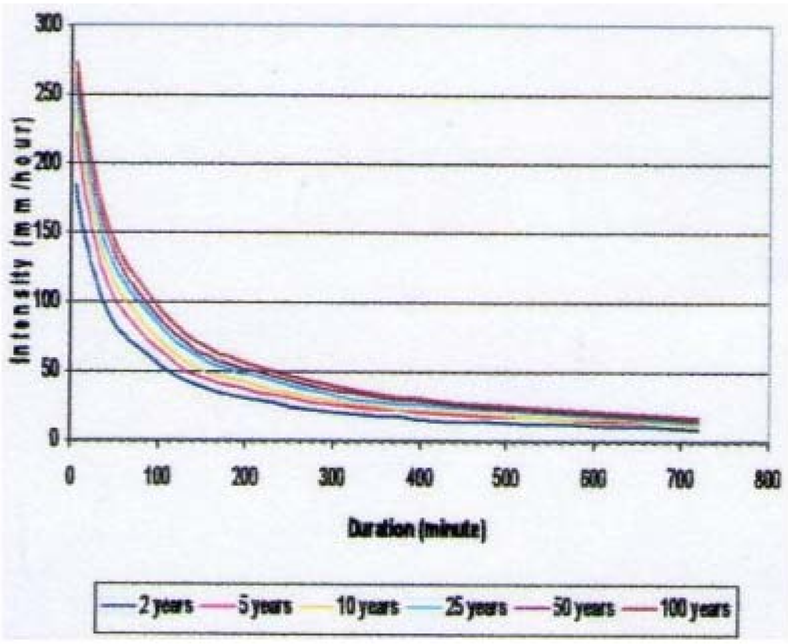


Figure 2.8. Typical Rainfall Intensity Duration Frequency Curve at Semarang Station

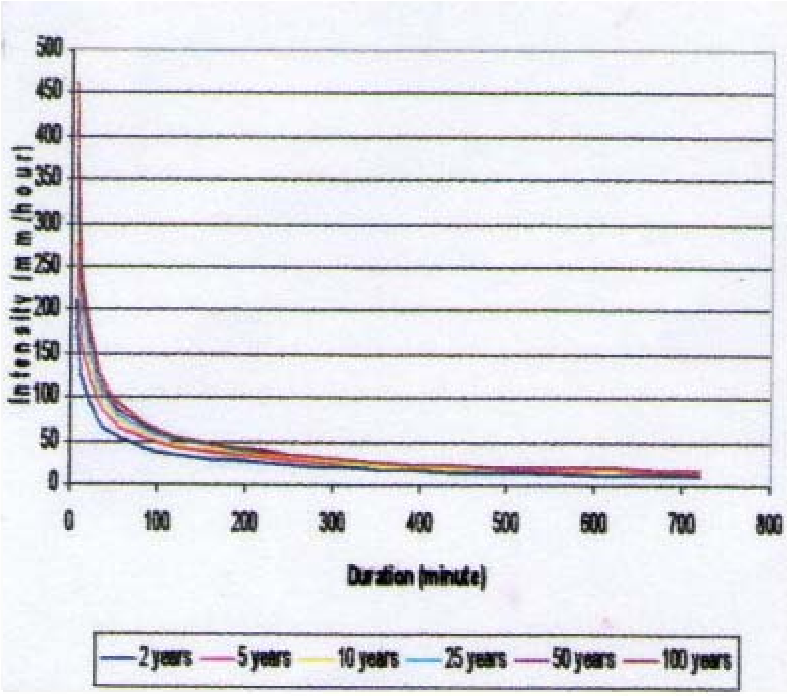


Figure 2.9. Typical Rainfall Intensity Duration Frequency Curve at Bali Station

e. Runoff coefficient

Runoff coefficient of a rainfall varies with topography, land functions, vegetation coverings, land type, and land humidity. When land functions vary in a watershed, consider each part of the watershed separately and calculate the weighted runoff coefficient value.

This next table contains the range of C value from various land-covering as typical reference. Appropriate value usage depends on individual judgement on the actual and anticipated condition of the watershed.

Table 2.3. Runoff Coefficient for Urban Areas

Type of Drainage Area	**Runoff Coefficient**
Comercial:	
- Downtown	0. 70-0. 95
- Residential	0. 30-0. 70

Residential:	
- Single Family Area	0. 30-0. 50
- Multi-Unit Area, separated	0. 40-0. 60
- Multi-Unit Area, joined	0. 60-0. 75
- Sub-urban	0. 35-0. 40
- Residential Apartments	0. 30-0. 70
Industrial:	
- Light Industries	0. 30-0. 80
- Heavy Industries	0. 60-0. 90
Park, Cemeteries	0. 10-0. 25
Recreational Spaces	0. 30-0. 40
Station Parks	0. 30-0. 40
Undeveloped Area:	
- Sandy loam 0-3%	0. 15-0. 20
- Sandy loam	0. 20-0. 25
- Loess 0-3%	0. 18-0. 25
- Loess 3-5%	0. 25-0. 30
- Loess >5%	0. 70-0. 80
- Thick sand area	0. 05-0. 15
- Steep cliffs with grass	0. 70
Pasture:	
- Sandy soil, flat 2%	0.05 – 0.10
- sandy soil, average 2-7%	0.10 – 0.15
- Sandy soil, steep 7%	0.15 – 0.20
- Heavy soil, flat 2%	0.13 – 0.17
- Heavy soil, average 2-7%	0.18 – 0.22

- Heavy soil, steep 7%	0.25 – 0.35
Roads:	
- Asphalt	0. 85-0. 95
- Concrete	0. 90-0. 95
- Pavement	0. 70-0. 85
Pedestrian Path	0. 75-0. 95
Roof	0. 75-0. 95

Table II.2.4 shows a systematic approach as an alternative to determine the runoff coefficient. This table is valid for open watershed areas with a series of aspects.

Table 2.4 Determining Runoff Coefficient

C	Extreme	High	Normal	Low
Relief - Cr	0. 28 - 0. 35 Steep, uneven, with average slope >30%	0. 20 – 0. 28 Hilly, average slope 10-30%	0. 14 – 0. 20 Wavy, average slope 5-10%	0. 08 – 0. 14 Relatively flat field, average slope 0-5%.
Infiltration - Ci	0. 12 – 0. 16 No effective covering, rocky or sandy covering with negligible infiltration capacity.	0. 08-0. 12 Difficult to absorb water, shallow clay or loam soil with low infiltration capacity or poor drainage.	0. 06-0. 08 Normal; light or medium soil texture, sandy loam with good drainage.	0. 04-0. 06 Good and very good; approximately 90% drainage area in the form of good pasture, forest, and such.
Vegetal covering - Cv	0. 12-0. 16 Barren or scarce vegetal covering.	0. 08-0. 12 Poor or clean cultivating for aggriculture >80%	0. 06-0. 08 Adequate to good; approximately 50% of area is pasture or good forest, <50% of	0. 04-0. 06 Good and very good; approximately 90% of drainage is good pasture,

			area aggricultured.	forest, or such.
Field Surface - Cs	0.10 – 0.12 neggligible; rare and shallow surface basin, no drainage swamp, steep and small.	0.08 – 0.10 Clear drainage system, without pools and swamps	0.06 – 0.08 Normal, surface basin as storage, pools and swamps.	0.04 – 0.06 Lots of surface storage, unmanaged drainage system, large floodplain, lots of pools and swamps.

Runoff coefficients are valid for rain with frequencies of 2, 5 and 10 years.

For larger frequencies, some modifications are needed because the infiltration and other reductions have smaller effect proportionally. Adjust the runoff coefficient with Cf factors such as shown in the table below.

The result of multiplication of C and Cf has to be <1.0.

Frequency (Year)	**Cf**
25	1.1
50	1.2
100	1.25

Rational equation becomes:

(Formula B)

$$Q = \frac{C.Cf.IA}{360}$$

Where:

- 360 = for calculation in metrics unit.

f. Rational Procedure

This next procedure describes the rational method to estimate the peak discharge:

1. Determine the watershed area (hectares)
2. Determine the concentration time, by choosing one of the formula, tp or tc such as the equation above, consider the development of watershed characteristics ahead.
3. Make sure of the consistency of supposition and boundary of rational method usage.
4. Determine the coefficient of rain intensity duration frequency (IDF).
5. Apply formula A on calculating individual rainfall intensity in mm/hour.
6. Choose the correct runoff coefficient of watershed.

If the watershed consists of several parts with distinct characteristics, the value of C of each individual part must be determined. C value is determined by using formula C. C value does not have a measurement unit.

(Formula C)

$$C = \frac{n = \sum_{n=1}^{m} C_n A_n}{\sum_{n=1}^{m} A_n}$$

Where:

C = weighted runoff coefficient

N = area part nth?

M = amount of area parts

Cn = runoff coefficient for area part nth

An = area of part (ha) # n.

Calculate the peak discharge of that watershed by using formula (B).

iii. Aspects of river hydrolics

Rapid rainfall concentration time only happens in a small river basin area with steep slope. This condition may be found in Order-1 channels with rapid or braided streams. Table 1 on page 17 mentioned that rapid segments have slopes >0.03 and braided segments have between 0.01 to 0.03. Those segments, especially the rapid ones will channel high velocity discharge with consequences:

- Spike of hydrograph where discharge suddenly increases rapidly and subsides just as quickly; and it also becomes the place on which discharge that will cause flashflood on its downstream (sedimentation segment) forms.

- Massive sediment transport capacity, both in amount and size of sediment grain.

2.2.2 Flashflood due to collapse of natural dam

Collapsed material of river banks (often mixed with vegetal debris such as tree trunks) enters and sits across the bed, forming a natural dam.

This natural dam will stop the flow of stream until certain heights, at which it will then collapse because of the elevation of water level on its upstream

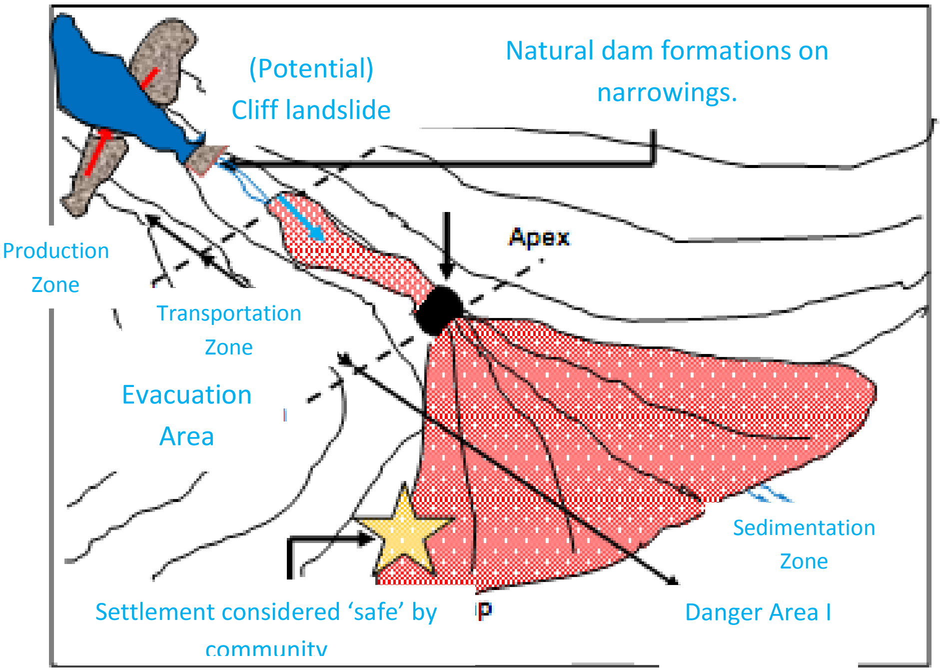


Figure 2.10. Flashflood Prone Area type 2

2.2.2.1 The formation of natural dam:

Natural dam is formed by materials from cliff landslide and vegetal debris. It mainly occurs on rapid streams due to its bottle necked area. Even on wide areas natural dams may occur if the landslide material is large enough and happen at once.

Two key elements affecting cliff landslide are rain intensity and duration, which will induce saturation and maximum pore pressure in the cliff materials.

Topography, land conditions, and river basin field coverings also hold major roles along the hydrologic factors mentioned above.

1) Types of land mass movement / slides:

a. River basin surface erosion. From a large river basin, the sediment from erosion contributes on the thickness of streambed deposit, but this mainly happen on the alluvial streams therefore it is negligible in the discussion of flashflood.

b. Creep: creep usually occurs on a more flat slope (<±10 degrees)

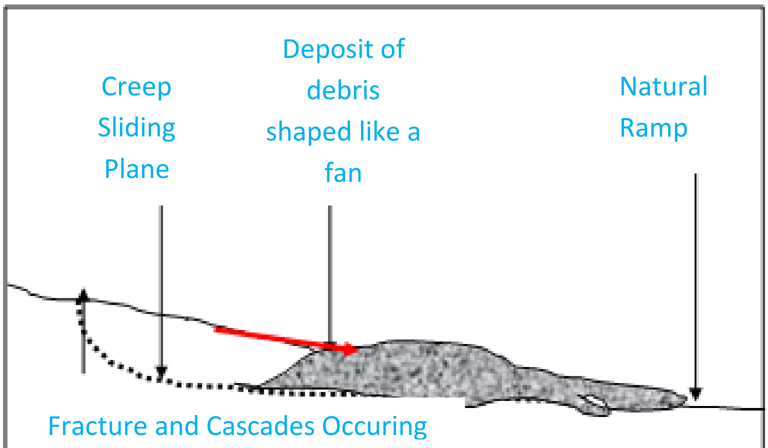


Figure 2.11. Slope of creep <10° or on impermeable soil.

On a ramp with impermeable soil, saturation runs very slowly. Creep as the preliminary movement requires a lot of time. It starts from the foot of ramp, which causes cracks and cascades on the peak of the ramp. This process increases the infiltration capacity through those cracks, accelerating the movement of land mass to become a landslide.

c. Landslide:

i. Landslide of the ramp occurs rapidly down which preceded by creeping.

ii. Or landslide of the ramp occurs after liquefaction of the surface layer of land mass.

Both processes will leave a sliding plane which is located quite deep underneath.

d. Cliff failure

Cliff with sloping angle of >45 degrees (cliff) collapses, It was triggered by the liquefaction process of approximately 2-3m thick surface layer. It may also occur due to the loss of counterweight on the foot of riverbank from stream erosion. It causes the top of cliff to collapse and contribute materials that form a natural dam.

2) Factors influencing the land mass movement /landslide:

Topographic and geologic factors became the two factors helping the ocurrance of land mass movement. Those two factors are related with the amount of infiltration capacity and saturation of cliffs and ramp areas.

a. Topographic factors

i. Plain land on top of a ramp or cliff that is relatively flat or with very gentle slope will have greater level of infiltrations, so that surface runoff heading to the ramp or cliffs is small.

ii. The existence of natural drainage channel or topographic features that may become drainage during rain which flows in paralel with the plane of ramp/cliff will absorp the water to the back part of ramp/cliff, and accelerate the saturation of the ramp/cliff.

iii. Vegetal cover

Good/heavy vegetal cover on river basin areas will increase the porosity of land surface by the soil penetrating roots. Besides, there will be resistence to runoffs by the vegetation, plus the humus layer absorps water and also reduce the runoff surface and increase the duration of absorption.

Those three conditions led to large degree of infiltration level, reducing soil saturation on the slope/cliff, rarity of cliff landslides and collapse of cliffs, and reducing surface erosion.

On this condition, landslide or collapse of cliff is caused by underground saturated water flow that searches for a way out (effluent) on a ramp/cliff, especially on heavy rain that occurs before the saturation of soil decreases.

On a bad/scarce vegetal cover or barren land, the catchment area is very small. Heavy runoff will run on top of ramp/cliff and led to massive erosions and will be absorped into the soil of ramp/cliff and quickly saturates it and causes landslides.

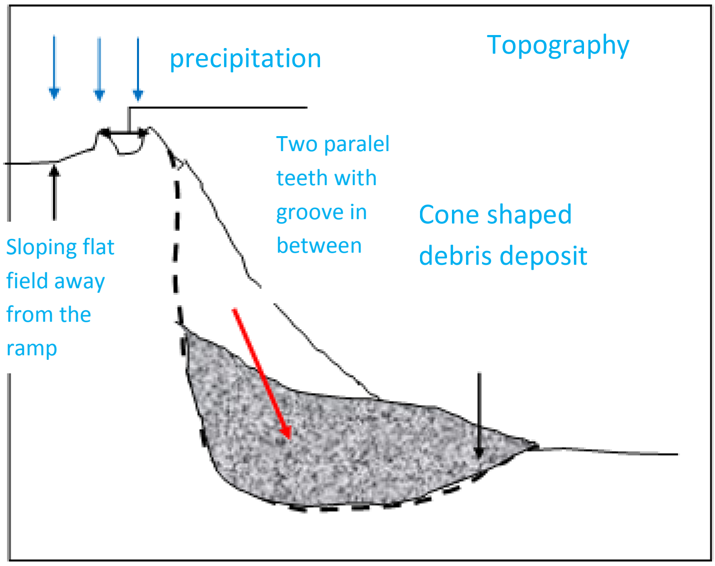


Figure 2.12. Topography Factors Effects.

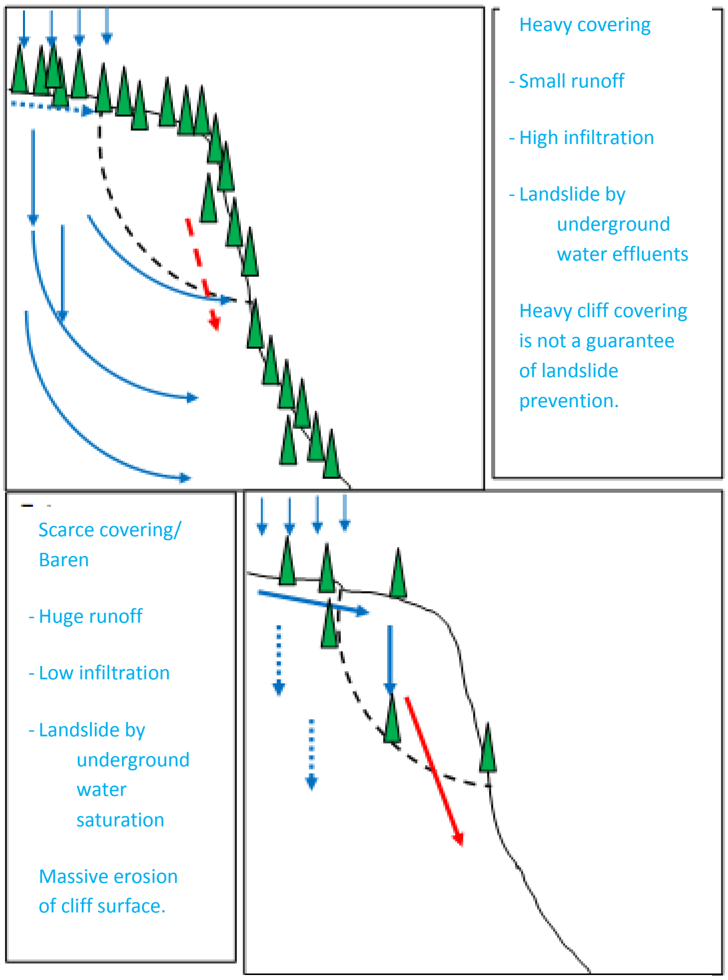


Figure 2.13. Vegetal covering effect on ramp/cliff stability

iv. Synclinal slopes:

Underground water in the back of synclinal slope and two anticlinal slopes flanking it will flow to the soil behind that synclinal slope, accelerating saturation and liquefaction process of the synclinal slope and causes landslide. Before the landslide, spring usually appears as an effluent of underground water. The appearance of this spring could be a sign of an impending landslide.

The spring can develop into stream after the occurance of landslide.

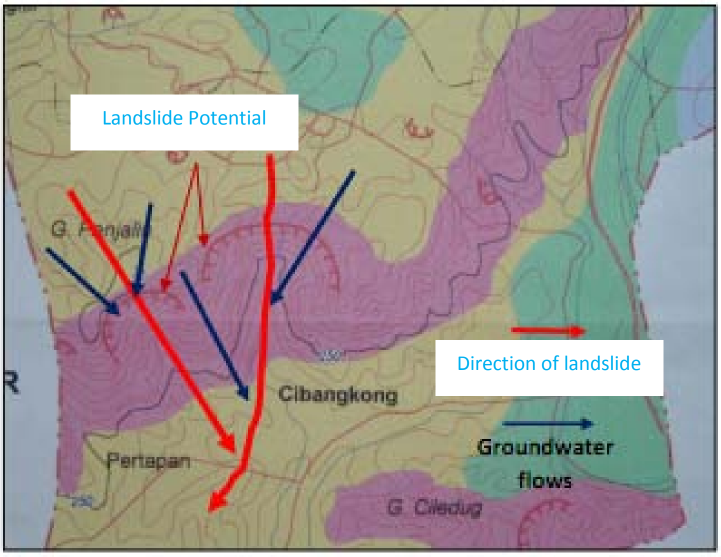


Figure 2.14. Landslide prone synclinal slopes.

v. River cliffs with extreme steep slopes which exceed the natural sloping angle of soil or the obsolete rock layer are vulnerable and may colapse, especially when the top layer of the cliff soil becomes obsolete and loose. With rainfall infiltration inside, the cliff soil will collapse.The cliff collapse is accelerated if its foot is eroded by the stream; hence the cliff loses its counterweight. The debris from cliff collapse will fall into the stream. With large enough amount of debris, it will form a natural dam, which oneday will collapse and cause flashflood that carries debris from the dam structure.

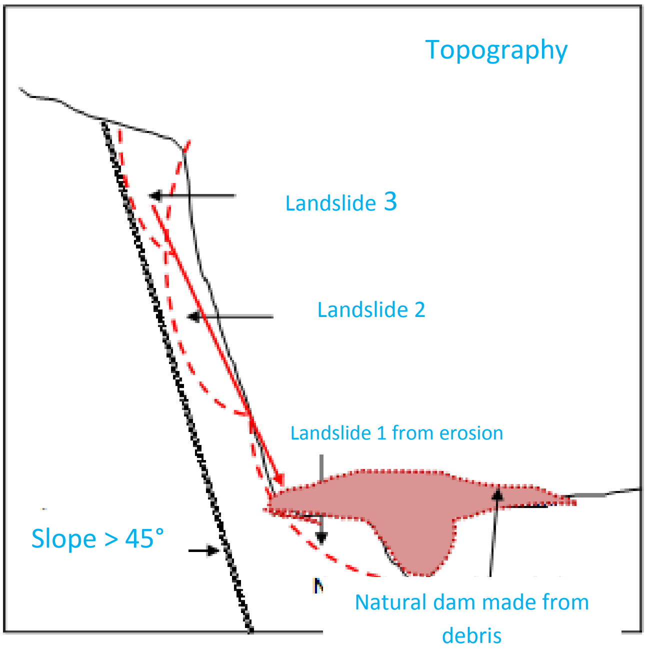


Figure 2.15. Cliff collapse by Topographic factors

b. Geologic factors:

When the subsoil of loose material is underlying the slope with large infiltration capacity, saturation of slope is easily achieved by repeated rainfalls. Water incoming from rainfall can no longer be absorped by the saturated subsoil, and will flow as effluent and led to cliff landslide.

Landslide process:

i. With increasing depth, the subsoil is getting denser; the absorption rate of horizontal flow is greater than its vertical flow. The upper part of the ramp saturates more quickly than the lower part, so it experiences earlier liqufaction and landslides, which will immediately followed by the lower part of the ramp.

ii. The opposite occurs when the vertical infiltration rate is greater than its horizontal rate, the lower part of the ramp will be saturated more quickly and liquefact and landslides in advance. It will immediately be followed by the upper part of the ramp.

Both of those processes go together quickly, catching up one another as if simultaneously occuring on the entire height of the ramp, or lagged within a certain time.

The landslide of a ramp will leave behind a deep sliding plane and a cone shaped deposit of debris material on the foot of the cliff.

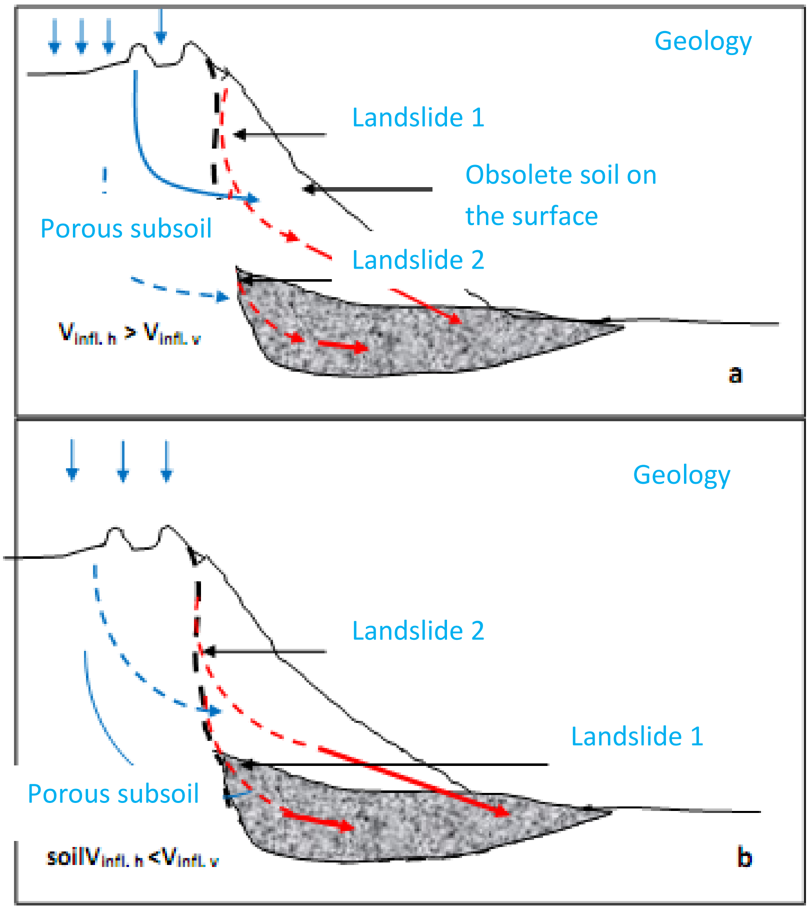
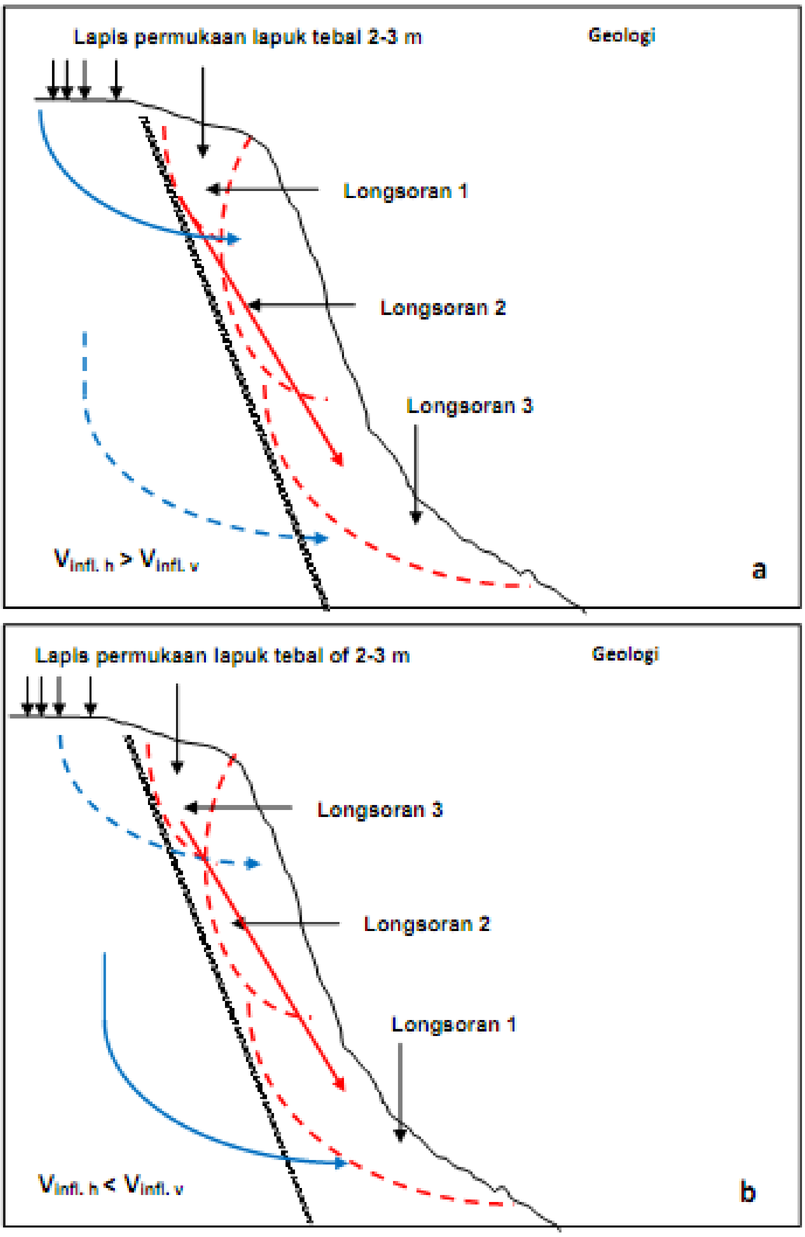


Figure 2.16. Contributing Geologic Factors



Gambar 2.17 Runtuhan tebing oleh faktor Geologi

i. Surface soil layer of the cliff is located on top of the impermeable sub surface. Water that enters the bordering plane between the two layers will make it more slippery and become the sliding plane of landslide.

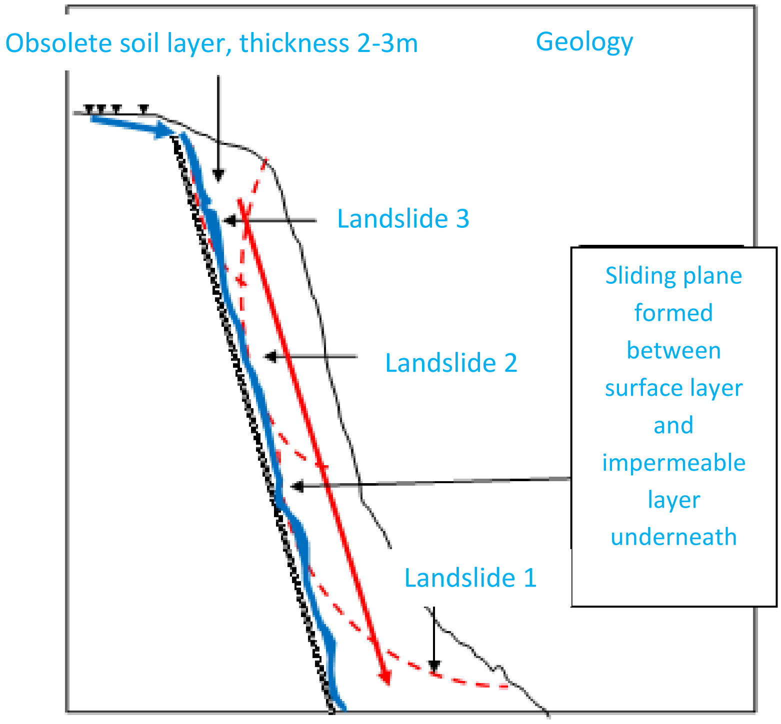


Figure 2.18. Sliding plane between two layers

2.2.2.2. Collapse of Natural Dam

The formation of natural dams are often times not visible to the public because the difficult terrain where the landslide occurs. This event is usually marked with thundering sound and shrinking of water discharge downstream,

The collapse of natural dam can occur by one or more of the following causes; it does not have to be preceded by heavy rain on streams even though it may trigger the process of rapid collapse.

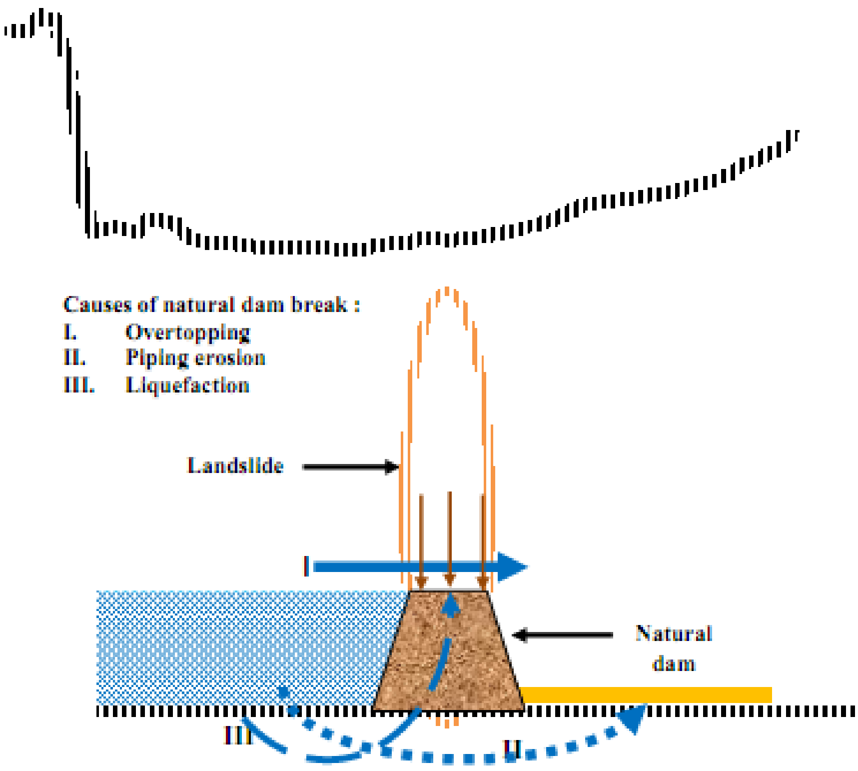


Figure 2.19. Sketch of natural dam collapse

If the height of water impounded in the upper stream has reached a certain elevation level, the natural dam will collapse because:

1. Overlying water runoff that will erode the body of the dam.

2. Piping erosion at the bottom or sides of the body of the dam due to insufficient density of the deposit.

3. Liquefaction or melting of the deposited materials of the dam due to water hydrostatic pressure inside the pores which exceeds the weight of the dam's body.

Ocurrance of the three causes above may be monitored from the murky discharge downstream, followed by thundering sound and rapid flashflood downstream.

III. Flashflood Mitigation System and Measures.

3.1 Flashflood mitigation measures

The main element of flashflood is large amount of water discharge occurring suddenly. This discharge on the production segment or torrential stream is able to carry debris deposited on the streambed or which it erodes while streaming.

Both elements may cause major disaster upon the affected area.

To reduce the threat and consequences of the disaster, some measures may be taken:

1. Diminishing the volume of flashflood

Figure 2.4 describes the leap of discharge caused by extreme rain which will cause flashflood downstream. To prevent it, a detention storage reservoir is made on the torrent stream and if necessary on braided stream to limit the discharge flowing down to a maximum of the dominant discharge of its alluvial segment downstream.

- i. Calculate the extreme discharge (Q1th, Q2th ...Q100th) with the procedure described in Rational Procedure subchapter.
- ii. Examine the stream capacity (Q dominant) downstream of the braided stream apex, to figure out part of the planned extreme discharge that needs to be dampened.
- iii. Calculate the flashflood volume of the extreme discharge that needs dampening.
- iv. Create calculation and relationship chart between elevation and stream capacity from the stream profile in order to determine the related capacity and elevation. (figure 3.1)

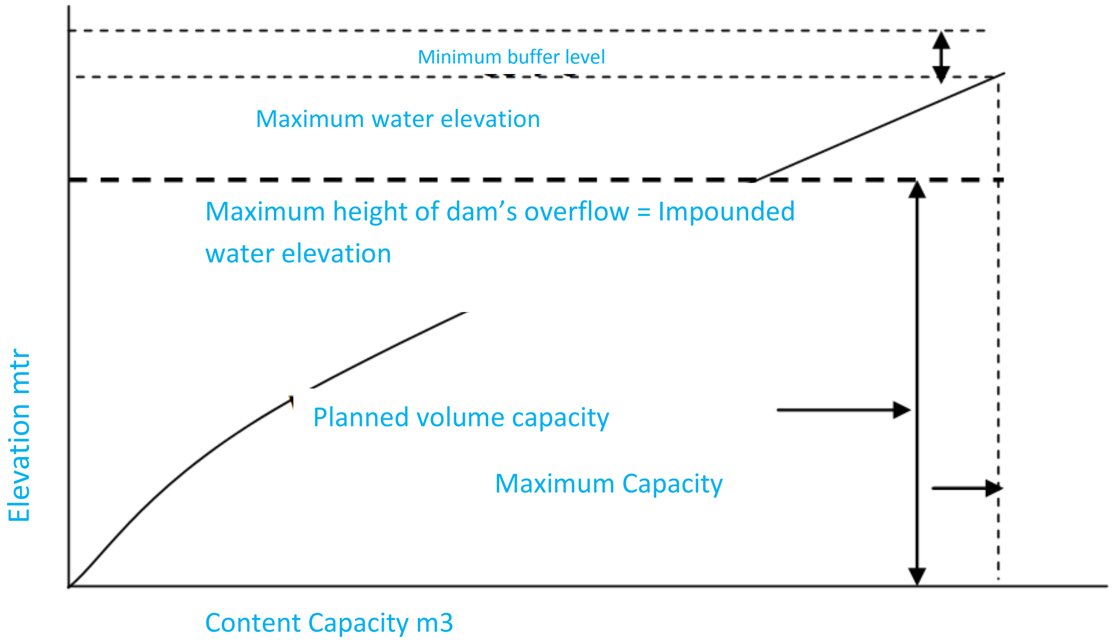


Figure 3.1. Elevation – Content Capacity Chart

2. In order to form a damper of flashflood, reservoir can be built by assembling a sabo building with the following specifications:

   i. Slit sabo type with single slit or double slits.

   ii. Culvert sabo type.

The cross section area of each slit or culvert has to be large enough in order to:

- Avoid clogging
- The flow rate on maximum discharge must be lower or shouldn’t exceed the critical velocity of material used in its construction to avoid damage.

   iii. The elevation of impounded water (see figure 3.1) is planned to create a certain levelo f pressure such that the slit discharge is equal to the Q dominant on downstream. This elevation can be equated to the elevation of overflow to save on construction and pressure level.

   iv. In determining the elevation of the overflow, one should make sure there is enough buffers should the water raises to maximum elevation.

Slit or opening of sabo building may be clogged; therefore water should be able to flow out above the overflow.

The maximum height of this overflow is planned to reach the maximum water elevation on Q dominant.

v. The maximum volume of flood dampening plan may be smaller than the available maximum capacity, so it may be necessary to build a series of flood dampening reservoirs.

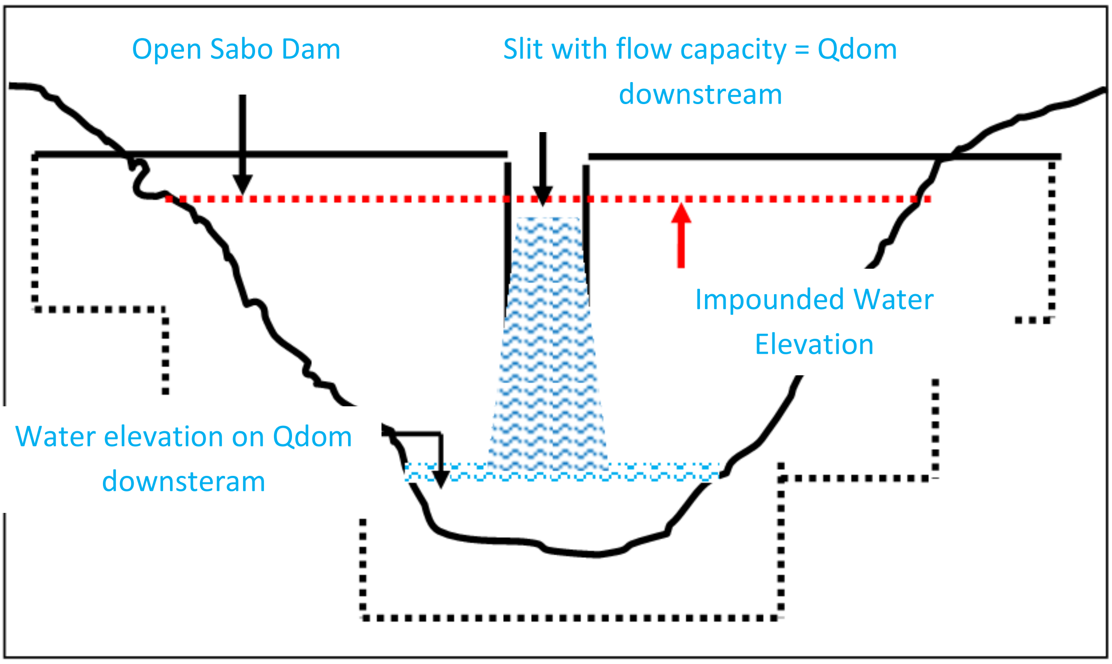


Figure 3.2. Flashflood Discharge Limiter Building, viewed from downstream

3.2 Flashflood mitigation system

To reduce the threat and consequences of flashflood, a system that consists of some measures can be done. The principles are:

1. Forming a flashflood dam on rapid streams to catch and store temporarily some of the flood volume (detention storage) in order to equalize the maximum released discharge with the dominant discharge downstream.

Flood damper can be made singular or in a series, depends on:

- The volume or frequency of flood that needs dampening and storing.

-The available volume capacity, which depends on:

- Slope and length of stream

- Height of cliffs along the torrent stream

- To increase the capacity of flood damper, damper may be built on braided stream flood if several conditions of its building are met, especially having adequate cliff height.

2. Create ponds on possible locations by taking advantage of erosion strains (gullies) as additional volume increase.

3. Reducing the flow rate of flashflood

The flow rate may be reduced especially on transportation channels by making it flow in tiers, with the installation of one or several (a series) of ground sills to flattened the slope of streambed. This measure will reduce the threat of debris flowing along the flashflood.

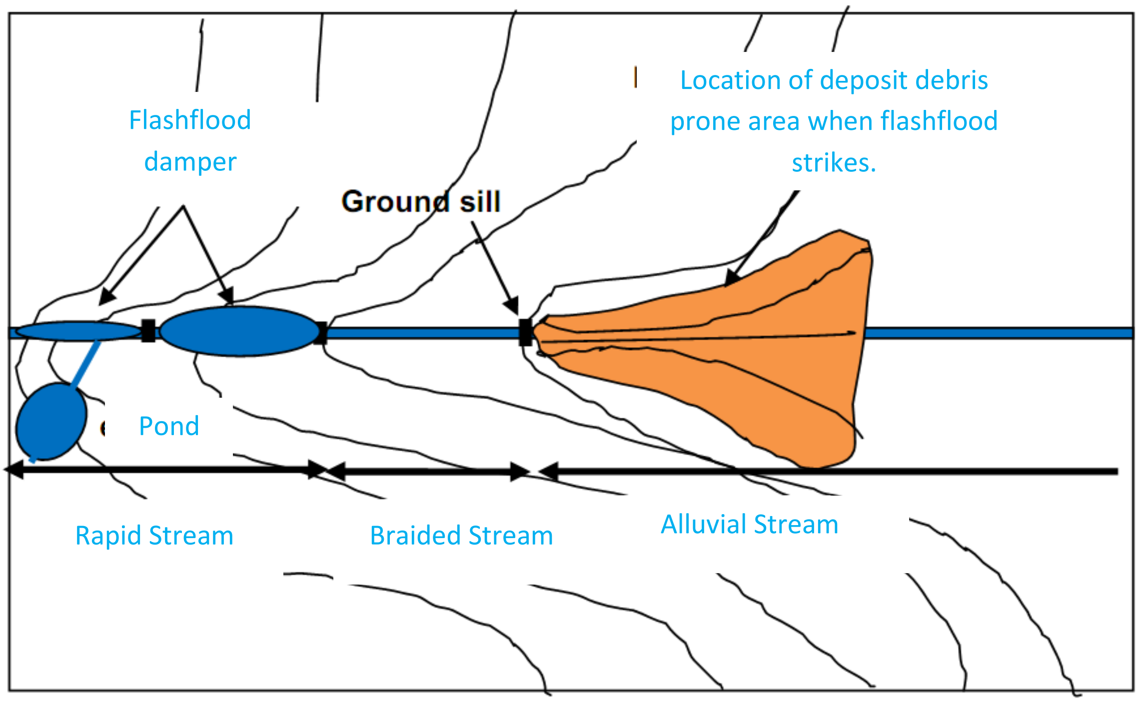


Figure 3.3. Sketch of Flashflood Damper

IV. EARLY WARNING ON IMPENDING FLASHFLOOD

Signs of impending flashflood:

1. Areas where flashflood has been recorded are considered as threaten areas. These area need to be specially monitored for signs of any possibility of another flash flood. Topographically and geologically such areas have special properties such described above. The properties of such areas can be used as an example to determine other flash flood prone areas. Those properties are:

a. River Basin Surface with steep topography.

b. Scarce vegetal covering.

c. Very eroded surface layer that reveals its lower impermeable layer.

d. Subsurface with low permeability and low infiltration level, so the surface runoff is high.

e. Very obsolete surface area. This condition is causing surface runoff and sediment yield which deposits on the streambed and may form a natural dam.

f. Heavy rain falls are frequently occurring for hours or days on these areas, causing soil saturation and eventually flashflood.

2. Signs of land mass movement / landslide.

a. Thunder on afar needs to be noticed because it signals the occurrence of storm in the upstream which may send massive runoffs that may lead to flashflood disaster without warning, especially on areas mentioned above on number 1.

b. Sudden increase of murkiness downstream, rumbling sounds from the stream may be a sign of a collapsed natural dam, or sudden loss of tree debris which may causes flashflood and debris flow downstream.

3. Warning of impending flashflood

There are two kinds of warning for flash flood:

a. Early warning based on local wisdom in marking when flashflood may happen in an area, such as the subside of stream discharge out of normal conditions.

b. Other flashflood warning are when a disaster happens or about to happen.
Warning of flashflood is stated when there is a heavy rainfall forecasted in a flashflood prone area, and evacuation effort may be done in lower areas if necessary. Do not ride vehicles on flash flood prone areas.

c. Several things that need to be watched for when one is in a flood prone area:

i. Be cautious of sudden heavy rain falls.

ii. Be cautious of rapid elevation of water level in the river.

iii. Do not cross the river when such elevation occurs.

iv. Flashflood may occur from collapse of dam or reservoir or sudden burst of impounded water.