GEOMORPHOLOGICAL ASPECTS OF FLOOD HAZARD

BY: DRS. NANETTE C. KINGMA

AGS: NATURAL HAZARD STUDIES
Floods and fluvial geomorphology.

- The passage of a flood wave through a river system constitutes a geomorphological as well as a hydrological event since floods may erode, transport and deposit large quantities of sediment as they move downstream.
Content.

- Introduction to flood hazard;
- Causes and types of flooding;
- Flood erosion;
- Flood sedimentation;
- River floodplain regime and stratigraphy;
- Factors controlling geomorphic response to large floods;
- Flood hazard mapping;
- Aspects of pre-disaster physical planning.
CHAPTER 1.
INTRODUCTION TO FLOOD HAZARD

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Definition of a flood.

- A flood is any high stream flow which overtops the **natural** or **artificial banks** of a stream.
- A flood is a body of water that **inundates** land that is **infrequently** submerged and in doing so causes or threatens to cause damage and loss of life.
- Flooding is a **natural and recurring** event for a river or stream.
Flooding is a natural hazard

- Potential **damaging** natural phenomena;
- Occurring with a certain **probability**;
- Within a **specific period of time**;
- In a certain **area**.
Flood Hazard Assessment

- Knowing the **pattern and behaviour** of rivers causing floods.
- In order to assess **Hazard Prone Areas**; the hazard and its characteristics!!!
- Provide information for flood disaster:
  - prevention;
  - preparedness;
  - relief.
# Munich Re Natural Catastrophe Service

## MRNatCat SERVICE

### 10 major natural disasters 1998 - worldwide

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Country</th>
<th>Economic losses Mio US$</th>
<th>Insured losses Mio US$</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.-10.1</td>
<td>Ice storm</td>
<td>Canada, USA</td>
<td>2,500</td>
<td>1,150</td>
<td>23</td>
</tr>
<tr>
<td>4.2</td>
<td>Earthquake</td>
<td>Afghanistan, Takhar</td>
<td>4,600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30.5</td>
<td>Earthquake</td>
<td>Afghanistan, Takhar</td>
<td>4,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.-15.5</td>
<td>Hailstorm, severe storm</td>
<td>USA</td>
<td>1,800</td>
<td>1,345</td>
<td>1</td>
</tr>
<tr>
<td>Mai-Aug.</td>
<td>Heat wave, forest fires</td>
<td>USA</td>
<td>4,275</td>
<td></td>
<td>130</td>
</tr>
<tr>
<td>Mai-Sept.</td>
<td>Floods</td>
<td>China</td>
<td>30,000</td>
<td>1,000</td>
<td>3,655</td>
</tr>
<tr>
<td>9.-11.6</td>
<td>Tropical cyclone 03A</td>
<td>India, Gujarat</td>
<td>1,700</td>
<td>400</td>
<td>10,000</td>
</tr>
<tr>
<td>Juli-Sept.</td>
<td>Floods</td>
<td>Bangladesh, India, Nepal</td>
<td>5,000</td>
<td></td>
<td>4,750</td>
</tr>
<tr>
<td>20.-30.9</td>
<td>Hurricane Georges</td>
<td>Caribbean, USA</td>
<td>10,000</td>
<td>3,300</td>
<td>4,000</td>
</tr>
<tr>
<td>30.10.-8.11</td>
<td>Hurricane Mitch</td>
<td>Central America, esp. Honduras, Nicaragua</td>
<td>7,000</td>
<td>150</td>
<td>9,200</td>
</tr>
</tbody>
</table>

NUMBER OF FLOODS 1987-96
BY CONTINENT

- Africa: 124
- Americas: 270
- Asia: 432
- Europe: 100
- Oceania: 56

FLOODS 982

DEATHS FROM FLOODS 1987-96
BY CONTINENT

- Africa: 6,200
- Americas: 7,249
- Asia: 227,612
- Europe: 3,878
- Oceania: 416

DEATHS 245,355
FLOOD DAMAGE 1987-96
IN MILLION DOLLARS

- Africa: 1,576
- Americas: 24,656
- Asia: 135,509
- Europe: 88,568
- Oceania: 349

DAMAGE
250,658

Figure B
Reasons for increasing annual flood losses-1

- Climatic change;
- Changes in land use:
  - urbanisation;
  - deforestation;
  - drainage and engineering works; e.g. canalisations
- Ground subsidence:
  - natural by geologic processes;
  - artificial by extraction of e.g. oil, gas, water etc.
Reasons for increasing annual flood losses-2

- Increasing population levels due to migration into marginal lands.
- Development of new floodplain land due to structural flood mitigation works - false sense of security.
Aspects of selective location

Many sites subjected to flooding are also subject to preferential location for industry, commerce and private housing; (accessibility, communication advantages and cheapness)

In upland areas; route ways for road and railway;
Flood characteristics & hazards.

- Depth of water;
- Duration of the flood;
- Velocity of the flood water;
- Sediment load of the flood water;
- Frequency of flooding;
- Discharge - peak flow;
- Rate of rise;
- Seasonality;

Not necessary independent of each other!!
Bridge collapse due to high stream velocity and high discharge.

05/03/2001
Castello de Paiva, Portugal
Flood extent.

- The areal extent of flooding and the depth of water are governed by the amount of discharge and the configuration of the local topography.
Impact of local geomorphology on flood extent.
Impact of geomorphological setting in the Netherlands-1

WAAL RIVER

SEEPAGE WATER

LOW LYING POLDER LAND

RIVER DIKE
Impact of geomorphological setting in the Netherlands-2

MEUSE RIVER

INUNDATED MEUSE TERRACES
CHAPTER 2.
CAUSES AND TYPES OF FLOODING.

Amount of Rainfall Necessary Within A 3 Hour Period To Cause Flooding (In Inches)

- < 0.5
- 0.5-1.0
- 1.1-1.5
- 1.6-2.0
- 2.1-2.5
- 2.6-3.0
- 3.1-3.5
- 3.6-4.0
- 4.0+
- NO DATA

SOURCE: River Forecast Center Flash Flood Guidance System
Flood causes.

- **Climatological:**
  - excessive levels of precipitation; high intensity and/or long duration / (antecedent moisture)
  - melting snow or rain falling on melting snow;
  - melting ice.

- **Climatological factor in combination with other factors:** e.g. causing estuarine floods and sea floods:
  - wind direction and strength;
  - intensity of low pressure systems
Flood causes-2.

- Climatological factor in combination with other factors (continu):
  - tidal stage;
  - the geometry of the sea basin;
  - the nature of the coast line.

- Other, only indirectly, if at all, with climatological events:
  - tsunamis produced by earthquakes;
  - river ponding behind natural dams caused by mass movements, glacial advances etc.
Flood causes-3.

Other, only indirectly, if at all, with climatological events (continu):

- failure of natural and man-made levees;
- failure of man-made dams;
- mass movements entering enclosed or semi-enclosed waterbodies;
- rupture of a glacial lake or release of subglacial water (GLOF);
- other.
Flood causes 4.

- Analyse causes and possible future causes of riverine floods.
- In relation to: magnitude / frequency / location / time period of occurrence / flood intensity conditions / factors typology of flood

  ➡️ defining diagnostic factors / parameters
  ➡️ defining monitoring schedule
Hurricane Mitch 1998.
Hurricane Mitch
Total Precipitation 10/25 - 11/17

Legend
- Extremely High (> 500 mm)
- High (300-500 mm)
- Moderate (150-300 mm)
- Moderately Low (<150 mm)

Rainfall data from Climate Prediction Center, NOAA
Flooding Probability

Total reported rainfall from hurricane Mitch is combined with flood prone zones to identify where flooding has a high probability of occurring.

Legend:
- High Flood Probability
- Medium Flood Probability
- Low Flood Probability
- Other floodplains (High Risk)
- Other floodplains (Moderate Risk)
- Other floodplains (Low Risk)

Rainfall data from Climate Prediction Center, NOAA.
Mitch Impacts:
Honduras Flooding and Landslides

- 7,000 Fatalities
- 5,000 Missing
- 33,000 Homes Destroyed
- 50,000 Homes Heavily Damaged
- 95 Bridges Destroyed
- 75 Bridges Heavily Damaged
- 70% Road Network Damaged Nationwide
FLOODING

- Tegucigalpa
- Sula Valley (El Progreso)
- Choluteca
FLOODING

Rio Chiquito

Dredging operation

Rio Choluteca at Mollo Bridge

Extreme sediment aggradation

Location of destroyed neighborhood

Tegucigalpa Stadium

Right bank downstream of El Chile Bridge

N.C.KINGMA  2/17/2004
Homes now 2 meters below channel elevation.

Rio Pelo

Pre-Mitch roadway
Tsumani flooding

- Turkey Earthquake: August 17, 1999 3:00am Magnitude-7.4.

Caused a tsunami in Izmit Bay:
- the Tsunami caused a maximum runup of 2.5 m along the northern coast of the bay and 1 to 2 m on the southern coast.

(http://www.usc.edu/dept/tsunamis/turkey/)
Izmit Bay, Turkey.
Buildings along coastline of Izmit Bay that are still flooded a week after the earthquake and tsunami.
FLOOD HYDROGRAPH STUDIES.

Drs. Nanette C. Kingma
Discharge and peak-flow.

- River flow is measured as discharge, the volume of water passing a point per unit time (m³/s).
- The largest flow is called peak-flow or peak discharge.
Drainage basin / network.

- Riverine flooding occurs within the drainage basin (also called: catchment or watershed);

Drainage basin divide.  Drainage basin
Types of runoff.

- Precipitation (P)
- Precipitation excess
  - Surface runoff ($Q_s$)
  - Direct surface runoff ($Q_{ds}$)
  - Subsurface flow ($Q_{ss}$)
- Losses
  - Infiltration
  - Other losses
- Other losses
- Percolation
  - Ground water discharge ($Q_g$)
- River discharge ($Q$) (total runoff)
Flood intensifying factors.

- Identical flood generating mechanisms, particularly those associated with climatological factors, may result in very different floods (from catchment to catchment or within a catchment form time to time).

- This is the effect of the flood intensifying factors.

- Flood intensifying conditions operate to speed up the movement of water within the catchment.
Flood intensifying conditions.

Interactions between climate, geology, soil type, vegetation cover, wildlife, and people's influence cause important differences in:

- Storage capacity
- Infiltration
- Transmissibility

Slope
- Flood control and river regulation works
- Roughness Load Shape Storage

Surface storage
- Under-drainage
- Channel length contributing or source area

Stable
- Pattern
- Variable

Basin characteristics
- Stable
- Slope Area
- Altitude
- Shape Aspect (bifurcation ratio)

Network characteristics
- Stable
- Variable

Channel characteristics
- Stable
- Variable
HYDROGRAPH STUDIES.

In hydrograph studies the relations between different sets of factors are investigated:

- physical parameters of the floods;
- climatic factors;
- physiographic factors (basin - network - channel).
Flood hydrograph.

- **T₁** = time beginning of rainfall to peak;
- **T₂** = time to peak

**Legend:**
- **Quick Flow**
- **Base Flow**
- **Arbitrary Flood Discharge Level E.G. Bankfull Discharge**
- **Rising Limb** (XY)
- **Recession Limb** (YB)

**Graph Elements:**
- **Peak Flow Reached at Time T = Y**
- **Time to Peak**
Unit hydrograph.

In order to compare different catchments the hydrograph has to be standardized into a unit hydrograph:

The hydrograph of storm runoff that is produced by a storm of known effective rainfall depth.

  e.g. 10 mm effective rainfall
HYDROGRAPH STUDIES.

Tokyo effect of urbanisation on hydrograph.

Predicted, 80% urbanisation.

Smith & Ward.
Time of concentration:

Time required for water falling on the most remote part of the catchment to contribute to streamflow at its outlet.

Flood intensifying conditions reduce the time of concentration.
Basin lag.

The time between the centre of mass of rain and the centre of mass of runoff.
Principle of equal duration.

- Different rainstorms with the same duration but with different intensities produce runoff for the same period.

\[ t_1 = \text{duration of effective rainfall} \]
Principle of proportionality.

- Different rainstorms with the same duration but with different intensities produce different volumes of runoff.

The ratio between the runoff is the same as the ratio between the intensities.
Principle of superposition.

- The time distribution of direct run off from a given storm is independent of run off from an earlier storms.
How to construct a unit hydrograph.

1a. Define baseflow component (green line);

1b. Subtract baseflow component from initial curve → red curve;

2. Define:

3. Effective rainfall

4. Duration: 10 hr

5. New scale B:

\[
\text{effective rainfall } \frac{A \times 10}{8.4} = \text{effective rainfall catchment}
\]
The shape of the hydrograph.

- The shape of the hydrograph depends on different factors:
  - Temporal and spatial distribution of the rainfall;
  - Shape of the drainage basin;
  - Basin relief;
  - Drainage density;
  - Permeability;
  - Retention characteristics; presence of lakes, frozen ground, deep soils etc. → antecedent moisture.
Aerial distribution of rainfall.

SLOW RISE

RAPID RISE
Effect of direction of storm movement on hydrograph.
Effect of aerial distribution of rainfall on hydrograph.

- Rain on steep slopes: quick runoff
- Rain on flat area: slow runoff
Effect of catchment shape on hydrograph
Effect of basin relief on hydrograph.
Effect of lithology on hydrograph.
River regimes.

- **Ephemeral river** with occasional flow.
- **Intermittent river**.
- **Perennial river**.

Types of streams
TYPES OF FLOODS

- Flash floods;
- Single event floods;
- Multiple event floods;
- Seasonal floods.
Flash floods-1

- An extreme, though short-lived, form of inundation;
- Associated with violent thunderstorms or cloudbursts;
- Storm lasts (usually) < 24 hrs;
- Rainfall intensity >>> infiltration capacity;
- Run-off rapid, hence streamflow nearly instantaneous;
- Common in mountaineous and desert areas.
Flash floods-2

Hydrograph: steep rise and fall;

Often destructive due to high sediment load.
Single event flood.

- Floods with a single main peak;
- Relatively simple hydrograph; substantially longer duration than flash floods
- Rainfall: several hours or days duration.
Multiple event floods.

- Duration of flooding extends over a periods of several weeks or months;
- Most disastrous type of flooding;

![Graph showing discharge over time from April to May 1957 for Colorado and Brazos rivers.](image)
Seasonal flood-1.

- Multiple event flood occurring annually in the wet season on a massive scale;
- Flood extending over several months;
- Often disastrous floods, sometimes beneficial.
  E.g Ganges, Brahmaputra rivers Bangladesh.
Seasonal flood-2.
Basic sciences involved in flood hazard assessment.

- Geomorphology;
- Hydrology;
- Meteorology;
- Soil science;
- Vegetation science incl. land use mapping