EWCE 461-SB

Rough / CT-1 08/07

Flood: Any flow that is relatively high and overflows out of the natural or artificial banks of any reach of a river.

Bangladesh's flood risk:

1. Deltaic country situated at the lower-end of GBM basin.
2. During wet monsoon seasons, overflowing rivers typically inundate 1/5 th to 1/3 th of the country's land.
3. Normal floods are a blessing (for agricultural reasons)
4. However, moderate to extreme flood events are capable of submerging up to 60% of the country's land.
5. Reasons being: flat topography, disproportionate catchment-to-country ratio (GBM basin's u/s in India, China, Nepal, Bhutan; d/s in Bangladesh).

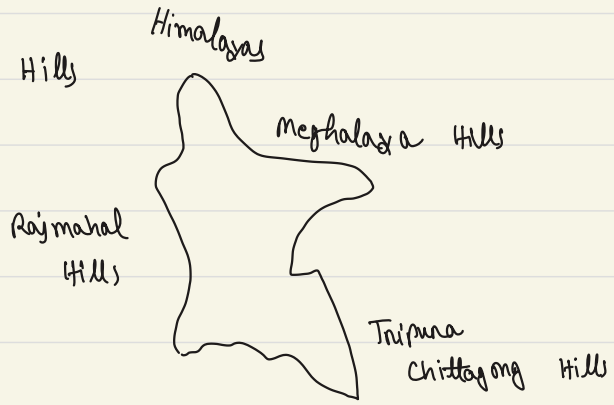
Types of floods: Riverine flooding - overbank, flash, levee break, ice-jam
Urban flooding
Mud flooding
Coastal flooding

Flash flood: Rapid and sudden rise & fall of water surface over a short duration. Unlike gradual annual floods, flash flood's hydrograph (stage v. time / stage on Y) exhibits frequent and sharp spikes in water stage due to immediate runoff responses.

Factors responsible for flood

Surrounded by mountains:

North — Himalayas & meghalaya Plateu Hills
west — Rajmahal hills
East — Tripura - Chittagong hills



Effects:

1. Snowmelt in Himalaya, in addition to rainfall runoff enters Bangladesh.
2. Monsoon wind that travels from Indian Ocean to Himalaya's slope, goes up then condenses and precipitates. which then enter Bangladesh as runoff.

Lower riparian country:

1. Bangladesh is located at the lower end of GBM basin.
2. GBM basin is roughly 1.75 M Km^2.
3. Of this large catchment, only about 7% is within Bangladesh but acts as the primary outfel.
4. Of the total water that flows into sea through Bangladesh, only about 9% is due to internal rainfall. Rest 91% is from u/s.
5. For comparison, annual volume of flow at the confluence of Brahmaputra & Ganga is equivalent to 5.52 m over 14.4 m ha while annual rainfall is ~2.3 m.

Floodplain country:

1. Low-lying and extremely flat floodplains associated with major rivers and their tributaries & distributaries cover ~80% of the country.
2. Tidal floodplains are about 1m el, major river floodplains are of 1-3 m el, and north-east sylhet basin has about 6m el.
3. Dhaka, being above 200km away from coast, is about 8m above MSL.

This flatness causes slight increase of water level result in inundation of vast adjacent lands.

Hydro-meteorological system:

1. Precipitation & subsequent streamflows are highly skewed over time. Around 80% rainfall occurs rapidly between May and September. As a result, wet monsoon phase exhibites floods and rest of the time water scarcity.
2. Around 230 rivers, most are tributaries and distributaries of three main rivers. When water stage of main river increase, its tributaries' flow results in elevation.
3. Brahmaputra river has the highest influence on flood Changes in its flow heavily affects country's flood.

Key determinants of extends of floods:

1. Magnitude : Overall depth, intensity, and distribution of precipitation at u/s dictacts baseline volume of water entering d/s as runoff.

2. Peak sync: When peaks of two or more major river coincides on a confluence, heavy flooding may occur. E.g., in 1998 and 2004, peak of GB synchronized.

3. Duration: Length of time water stage of main river remains high, adjacent floodplain face flooding.

4. Boundary control: Final outlet acts as a physical check on how quickly water can pass. E.g., due to spring tide and monsoon wind, water level at coast increases, which causes backwater effect, lifting u/s water level.

Causes of flood in Bangladesh:

1. Excess rainfall
2. Deteriation of drainage channel (natural)
3. Effect of unplanned obstacles
4. " " embankment
5. Deforestation in u/s
6. Coincides of peaks.
7. Failure of retaining struct.
8. Global climate chng.

Urban Flooding: Inundation of land or property on a built-up env due to storm water by exceeding drainage capacity.

Causes:

Natural;

1. Heavy rainfall
2. Flash flood
3. Lack of reservoir
4. Silting

Man-made

1. Deforestation
2. Unplanned urbanization
3. Population pressure
4. Lack of flood control measures
5. Poor water & drainage management

Impacts:

On economy:

1. Structural damage & assets
2. Earning & employment
3. Market & supply disruption
4. Post-flood recovery cost

On environment:

1. Destruction of urban greenage
2. Imbalance

On human:

1. Displacement & mortality
2. Psychological trauma
3. Epidemic outbreak

On traffic:

1. Destruction of infrastructure
2. Congestion

On livestock:

1. Neglect

Preventive measures:

1. Sustainable urban drainage
2. Plant trees
3. Rainwater harvesting
4. Planned urbanization
5. Regulate land use & development
6. Floodplain management
7. Construction of flood protection struct.
8. Improve drainage capacity

Rough / midterm

15/08

Lec 3: Flood management measures & dam engineering

Scopes:

- [x] 4 phase disaster management cycle
- [ ] Short-term vs long-term; structural vs non-structural measures
- [ ] Why full flood prevention is unfeasible in Bangladesh
- [ ] How submersible embankments operate
- [ ] Labelling of structural parts
- [ ] Defn & distinction between various dams & weirs
- [ ] Diff btwn various dams

Flood management planning: (4)

Mitigation → Preparedness → Response → Recovery

- Mitigation: Involves measures to avoid or reduce the impact of a flood event. Including installing structural barrier and raising awareness on what to do during flood.
- Preparedness: Developing execution plan on how to react to a flood event. Includes training emergency relief personnel, installation of warning system.
- Response: Comprises emergency activities carried out during and immediately after a flood event. Includes emergency aids delivery, evacuation to predesignated locations, and measures to avoid / minimize secondary damage.

- Recovery: Focuses on restoring vital life support system to minimum operational level and providing rehabilitation support until affected community returns to normal life.

Flood management measures: by implementation timeframe

Shord-term measures: To provide immediate relief to high risk locations: (4)

- Construction of embankment along riverbank
- " " raised platform for shelter
- Dewatering via pump if gravity drainage restricted
- Erecting floodwalls near congested zones

Long-term management: (3)

- Storage reservoir to moderate peak discharge.
- Integrated watershade management system in hilly area to reduce runoff, soil erosion
- Hydro-geomorphological flood forecasting & early warning system.

Factors affecting flood damage: (5)

location, depth, duration, timing, flood extent

rural/urban diff — of crop growth — submergence tolerance — crop calendar

Flood management measures: engineering interwention

Structural measures: six categories

direct

1. Storage reservoir: attenuate peak hydrograph
2. Retarding basin: reduce d/s water depth by retaining flood water on basin at d/s.
3. Flood wall: confine flood water
4. Channel capacity improvement: dredging, widening, removing obstructions
5. Diversion channels: re-route to secondary channel.
6. watershed management: vegatative, soil conservation works.

Non-structural measures: seven categories

1. Flood forecasting & warning
2. Floodplain zoning
3. Flood proofing
4. Flood fighting
5. Reservoir operational rescheduling
6. Reservoir programs
7. Flood insurance

Measures for flood-control in Bangladesh:

[mitigation of flood damage than flood prevention]

1. Early forecasting
2. Effective transmission of flood warning
3. Zoning law
4. Public education
5. Disaster relief
6. Effective operational scheduling of reservoir weirs
7. Involvement of local people for cons. of new embankment

Structural measure: Dam

Dam: A barrier constructed across a channel to hold and control the flow of water for various purposes such as flood control, hydropower generation.

When dam is required:

Flood control
Drinking & domestic water supply
Irrigation water
Industrial water supply
water quality imp.
Sediment retention/ erosion control
Inland nav, recreation
Hydro-electric energy generation
Temporary worksite dewatering

Classification of dam:

By structure: Arc dam
Gravity dam
Arc-gravity dam
Embankment dam
Barrage dam

By size: Large dam
Major dam

By function: Detention dam
Diversion dam
Weir
Dry dam
Saddle dam

By material: Timber dam
Steel dam

Other: Coffer "
Natural "
Beaver "

??

reduce v incr. v
↙ prevent erosion ↙ prevent sedi..
check dam & wing dam
Tailing dam
↖ mining

Flood control projects in Bangladesh:

1. Full protection embankment: Embankment along the entire length of riverbank
2. Partial protection embankment: Low ht submesible embankments designed to delay pre-moonson flooding just enough to ensure safe winter crops harvest.
3. Gravity drainage regulation & sluices: Sluice to prevent external river backflow when stages are high. Then drainage through gravity when stage drops.
4. Pumped drainage: when gravity drainage not feasible.
5. Project category: Flood control (FC), FCD, FCDI, D
   - FCD → drainage
   - FCDI → irrigation

Rough / Final

23/10

Flood management

Lec 1 Overview, types, causes

GBM basin → Ganges, Brahmaputra, Meghna

Flood → any flow that is relatively high and overflows into adjacent banks or floodplain may be called a flood.

Blessing → normal floods
provides vital moisture and fertility to the soil through alluvial silt deposition.

Types of flood → Riverine flood
→ overbank flood
→ Leeve or dam break
→ Flash flood
Urban flood (storm water / drainage)
Mud-flood
Coastal flood

Factors responsible for floods:

2. Surrounded by mountains:

→ On East is Chittagon Hill tracts
North is Himalay
West is Rajmahal Hills

Their rainfall + ice melting discharges into Bangladesh → flood

During June to September, warm moist air from Indian ocean travels to the Himalayan slope raises up and cools down which ends up as orographic rain, and enters Bangladesh as runoff.

2. Lower riparian country:

Of the GBM basin, only 7% area is within Bangladesh.
Rainfall over the whole basin is a principal cause of flood in Bangladesh.
Of the total discharge into sea, 91% comes from outside Bangladesh.

3. Floodplain country:

Extremely flat topography; Dhaka is only about 8m above MSL while it is 225 km North of sea.
Floodplain is about 80% of the country
Mean el. is 1–3m on main rivers (flat)

4. Hydro-meteorological system:

Excess rainfall from May to September (80% of total rain)
low to no rain rest of the period.
Highly skewed.
230 rivers; most connected to each other

All rivers are tributaries or distributaries of major rivers.
High water lvl on major rivers causes backing up of water on tributaries.
B-G carry 85% of flow entering Bangladesh.

Key determinants on the extent of flooding:

1. Magnitude & peak synchronization → in B-G river
2. Duration of floods in major river
   D/s control is provided by lower meghna
   BoB causes strong back water effect.

Major types of floods:

1. Flash flood
2. Monsoon flood
3. Drainage congestion
4. Storm surge in coastal belt.

Lec 2: Flood processes in urban & rural area

storm water vs. flood:

1. Direction → S: flows towards channel
   F: overflows from channel
2. Size → S: < 1 sqmile
   F: > 1 sqmile
3. Nature → S: natural large channel
   F: small man made
4. S: discontinuous
   F: cont.

Urban drainage pros & cons:

Adv: 1. Dispose storm water or liquid waste
2. Prevents water logging by carrying water as quickly as poss.
3. May also convey industrial wastewater.

Disad: 1. Floods when overwhelmed
2. Discharges pollutants in natural stream

Urban flooding:

Inundation of of land and property on built-up area due to overwhelming of drainage system.

Causes of urban flooding:

Manmade: Unplanned urbanization
Reduction of permeability due to pavements
Population pressure
Deforestation
Lack of flood control measures
Inadequate water or sewage management

Natural: Excess rainfall
Flash flood
Lack of reservoir
silting

Impacts of urban flooding:

On economy: i) Infrastructure and asset damage
ii) Disruption of commence and earning
iii) Market inflation
iv) Fiscal burden

On human: i) Causality and homelessness
ii) Psychological distress
iii) Disease outbreak

On livestock: i) Neglect & mortality

On transport: i) Damage to road or tracks
ii) Inundation of road or rail tracks
iii) system wide congestion & delay

On env.: i) Loss of greenary
ii) Ecological damage iii) Pollution

Preventive measures:

Drain → absorb → structural → plan

Drainage: i) Urban drainage system
ii) Improve drainage efficiency

Absorb: i) Rainwater harvesting
ii) Plant trees (permeability, evapotranspiration)

Structural: i) Flood control measures
Flood wall, levee, embankment
ii) Retention basin, sluice gate

Plan: i) Urban planning
ii) Floodplain management
iii) Land use & dev. planning

Lec 3: Flood management measure

Planning:

1. Pre-disaster mitigation: Installation of measures to reduce or prevent flood event → structural or public edu.
2. Pre-disaster preparation: Develop response plan, install warning system, assign who'd response and how, train.
3. Flood response: During flood evt; provide emergency relief, move to shelter, flood fight.
4. Post-flood relief: Provide support until return to normal.

Flood management measures:

Short-term:
i) Embankment to banks subject to freq flooding
ii) Raised platform → temp shelter
iii) Dewatering
iv) Flood walls

Long-term:
i) Dams and reservoir to reduce peak
ii) Integrated watershed management
iii) Flood forecast and warning system based on hydro-geomorphological studies.

Factors for damage from flood evt.:

i) location → urban / rural
ii) duration
iii) timing
iv) depth
v) extent of flooding

In/direct measures:

Direct/ structural:
i) Detention basin
ii) Retarding basin
iii) Floodwalls, leeves
iv) Diversion channel
v) Improve channel cap
vi) Remove obstacles
vii) watershed management

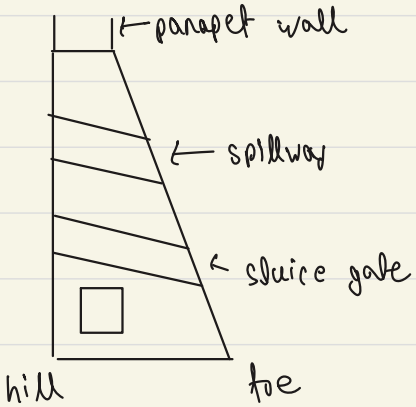
Indirect / Non-struct.:
i) Flood forecasting / warning sys.
ii) Flood fighting
iii) Flood insurance
iv) Post-flood recovery prog.
v) Floodplain zoning
vi) Reservoir rescheduling
vi) Flood proofing

Flood control policy → damage mitigation
not flood prevention

Structural measures:

Dam: Barrier built across a river or channel to hold water.
for may be drinking, hydropower generation, irrigation, sediment ret.

Components: hill
toe
abutment
spillway
sluicegate
gallery



Types of dam:

Structure → Arch, gravity, arch-gravity, embankment dam, barrage

Size → Large dam, major dam
h>15m h>150m

Use/func → diversion, saddle dam, weir, check dam, dry dam, underground dam

material → timber, steel

Other → coffer dam, natural dam

Recap: By use -> storage dam
detention dam
diversion dam
dry dam
check dam
saddle dam
wing dam
tailing dam
wein
barrage

wein vs. barrage:

W: fixed raised crest
B: adjustable gates

W: High afflux u/s
B: minimal afflux u/s

W: silting occurs
B: less & can be easily flushed

W: low cost, simple
B: high cost, mechanized

Dam vs. weir

D: high head
W: low head

D: doesn't overflow
W: deliberately overflows

D: long term storage, large cap
W: minimal storage

D: multi-purpose
W: flow measure, diversion, ...

Flood control projects in Bangladesh:

i) Full protection embankment: along the entire len of bank
ii) Partial protection: embankment designed to be submerged during monsoon but delays the flooding just enough for safe winter harvest
iii) Evacuation of water by gravity through sluice gate and drainage.
iv) Pumping
v) Project classifications: Flood control FC
" " & Drainage FCD
" " , " , & Irrigation FCDI
Drainage proj. D

gravity drainage regulation & sluices

prevent inflow, drainage

Lec 4 Diversion channels & floodways

Diversion channel: Divert water from main channel for the purpose of flood control, municipal water, irrigation, etc.
E.g; flood ways

Flood ways:

Man-made structure that offers a different route for excess water to travel; mitigates eff. of flooding

They can divert to a different water way or return back the water into main channel d/s after concerning area.

Adv.: i) Direct flood mitigation and community protection.
ii) If used for periodic flooding only, then diversion channel remains dry other times and can be used for recreational activities, grazing, etc.
iii) Low-lying land or abandoned riverways can be reused as diversion channel, restoring their ecological status.
iv) High stage on the main channel can be controlled, ensuring flow with channel capacities.

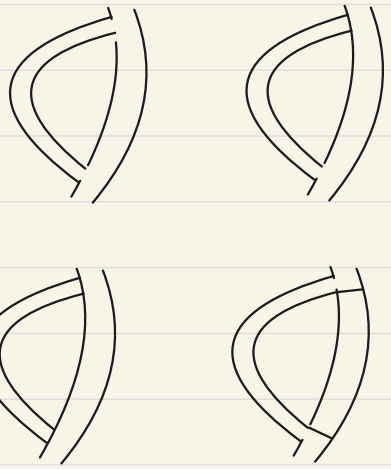
Disadv. :

i) Bed & bank erosion : div. channel may have higher bed elv., high velocity → bank erosion
ii) Large right of land
iii) Permanent inundation if invert is too low
iv) Sediment deposit at d/s of main channel if diversion channel returns flow there.
v) Loss of existing ecology / habitants.
vi) Main channel stability
vii) Laws & regulation for inter basin water transfer.

Classification of river diversion :

i) Diversion in tunnels
ii) " in conduits
iii) " in channels
iv) Bypass channel
v) Temporary / lateral constriction

Permanent & temp div.



Design considerations:

Hydrological & hydraulic:
i) Catchment scale & flow rates
ii) Base flow & peak flow variation w/ seasons
iii) weather & storm evt.
iv) External inflow
v) Invert & slope
vi) Tributary invert el.

Right of land: i) Land use and space availability

Ecological: i) Doesn't disrupt existing life

Risk & consequence: i) Public safety
ii) economic
iii) env.
iv) delays
v) regulatory

Construction scheduling

Emergency preparedness: if impeding flood peaks during construction emergency action plan — halt work, reach elevated safe ground.

Floodwall: vertical artificial barrier to hold or contain water of a waterway that may rise to unusual lvl during flooding or extreme evts.

Floodgates → opening

High cost (justified by properties it protect)

Lec 5 Dredging

Defn: An excavation activity that is carried out at least partly under water.
Done in shallow water areas with the purpose of gathering up sediments and disposing of them.

Dredger: A piece of equip that can dig, transport, and dispose of water lying sediments.

Purpose:
i) Channel deepening and maintenance
ii) Beach building
iii) Aggregate mining
iv) Land reclamation

Steps:
i) Pretreatment — chemical or mechanical or hard rocks
ii) Extraction — disintragation of soil, movement in transportation
↙ hydraulically or mechanically
(iii) Disposal

Types of dredging: (i) Mechanical dredging
Involves removal by bucket
Place the mat on a barge, and tow the barge to disp.
(ii) Hydraulic dredging
Involves suction pipes
Deposit into upland through pipe

Lec 6 Land/watershed management for flood mitigation

Defn: Process of managing the use or development of land resources.

Why impo, compared to others:

Structural measure → design, construct, maintenance
time consuming and also expensive
doesn't completely eliminate flood risk

mix of struct. & non struct. is proper soln.
↳ land-management

watersned management:

Study of relevant chars of a watershed aimed at sustainable distribution of its resources, creating and implementing plans, projects, and enhancements that affect its people, plants, and animals.

watershed modelling:

Parameters: size shape physiography drainage vegetation
hydrology geology hydrogeology Landuse
socio economics

Constituents: (input output transformation) function

Steps: formulation → calibration → application

Model classification:

i) Blackbox models: Describe rainfall and surface runoff relation purely mathematically w/o entailing physical process.

ii) Distributed models: Based on complex physical theories (e.g., solving unsteady flow eqn).

iii) Lumped models: Intermediate position between blackbox and distributed models.

Concept of IWM:

i) Integrated management: multiple uses → manage in integrated manner.

(ii) Decentralized; manage at lowest admin or community level

(iii) Stakeholder inclusion

(iv) Treat as economic asset, water

Strategies:

i) Long-term sustainability

ii) Equitable access

iii) Demand management

iv) Env protection & restoration

Effects of development interventions on flood hazard:

Transportation:

1. Roads are usually elevated than surrounding ground level.
   To water, they work as obstacles.
   If road is on floodplain, or close to river, it can constrict the flow area, forcing water to flow faster.
   Can impact both u/s & d/s
2. Bridge or culvert, transverse to flow direction. Also obstruct.
   Fail to address parallel flood flow → backwater eff.

Land-use: Urban → impervious layer
less infiltration → flood

Agricultural: Trenches, drainage work, pipes → impact
Top-soil compaction
Type of crops and amount
slope of field.

Flood management: aims to maximize the efficient use of floodplains while reducing the loss of lives from flooding.

Land use planning process:

1. At highest admin lvl → specify general aim for future
2. At district lvl → specify required land uses under its jurisdiction.
3. At local lvl → Assign detailed land use to individual parcels.

Building standards:

1. Freeboard above fld lvl
2. Foundation erosion protection
3. Oriented to least flood flows
4. Limit enclosure to part of building below flood lvl.

Lec 7 Flood proofing

Defn: Process of reducing damages to a structure or contents of building in flood hazard area.

→ raising building fdn above flood lvl
→ surrounding w/ floodproof concrete walls
→ sealing all openings below fld line.

Based on type of protection

→ Permanent measure
→ contingent "
→ Emergency "

Adv. → Doesn't need waiting for govt
→ Much more cost eff. than flood risk
→ Doesn't req land (as be needed by flood walls or dikes)
→ Less likely to fail

Disadv. → Req current knowledge of flood hazard, mapping, warning.
→ Eff for low flood lvls only
→ Does not to high vel flow.

Considerations for development of flood proofing strategy:

1. Flood hazard analysis: depth of flood, flood flow velocity (force of impact), duration of flooding, warning time.
2. Site chars: potential for local flooding, soil type
3. Building chars: foundation type, wall material, building age, structural cond.
4. Appearance
5. Accessibility & human intervention
6. Cost/Benefit analysis: upfront + maintenance cost against reduced flood damage.

Flood proofing strategies outlined by FEMA:

2. Elevation: elevate the building to a new ht so that lowest floor is above flood lvl. Done by raising the entire building on constructing a new elevated floor inside.

2. Relocation: move the building to a new higher ground out of hazardous area. Done by placing it on a trailer to re-placing on the new land.
Requires purchase of new land.

3. Wet flood proofing: Allow flood to pass through the building by utilizing an uninhabitated basement on floor, ensuring inside and outside hydrostatic pressure cancels out.
Requires extensive cleanup afterwards.

4. Dry flood proofing : seal the building's exterior walls with impermeable sealants, membranes. Also placing removable flood shields at entrances.
Applicable if flood depth < 3'.

5. Levees and flood walls : surround a single or group of buildings with raised barriers so that water doesn't enter the vicinity.
Require internal drainage
Levees → natural materials
Floodwall → narrow walls of concrete

6. Demolition : Tear down the structurally damaged or weakened building and rebuild at the same place or elsewhere.

Lec 8 Flood zoning

Defn: A non-structural measure of flood that identifies areas of varying flood hazard

Adv.: Reduces the risk and cost of damages flood causes:

i) Passing zoning law restricting land use, prohibating building construction

ii) Mandating specific construction material use by building standards to reduce damage.

Disadv.: i) Can't expand urban area if no building sites
ii) Don't apply if existing buildings present.

FIRM: Flood Insurance Rate Map
supports the National Flood Insurance Program

Flood zone classification:

→ zone 1: Low probability
Riverine or sea flooding → 1 in 1000 annual or less

→ zone 2: Medium probability
Riverine flooding → 1 in 100 to 1 in 1000 annual
sea flooding → 1 in 200 to 1 in 1000 annual

→ zone 3a: High probability
Riverine flooding → 1 in 100 annual or more
Sea flooding → 1 in 200 annual or more

→ zone 3b: The functional floodplain → land where water flows or stands in times of flood.

Approaches of flood zoning:

→ historic approach: Past events
written reports, photographs, old maps

→ conventional approach: Use high-water marks on buildings and reported cases in news media

→ modeling approach: Use design floods and flooding process

Data required:

i) Topography
ii) Elevation
iii) Hydrological
iv) Hydraulic
v) Land use Land cover
vi) Socio-economic
vii) Past flood

Lec 9 Flood hazard mapping

Risk: Probability of a flood with given intensity and given loss to occur in a specific area.

→ hazard & vulnerability

Hazard: Probability of occurance of flood

vulnerability: Degree of loss to a given element or set of elements (0 to 1)

Elements at risk: people, property, livestocks, structures, economic activities.

Methodology:

→ Hazard: H

→ Damage, D = ΣEV

→ Risk, R = HD

$R = \Sigma HD$

Recap:

Flood Risk: Expected loss resulting from the interaction of flood hazard and vulnerability.

Flood hazard: The exceedence probability of given flood to occur within a specified period of time.

Elements at risk: Count on economic value of population, prop, economy located within the inundation area in return period.

Susceptibility: Answers "how the exposed elements be damaged"; from relative damage fun' on curve.

Flood vulnerability: Degree of damage to set of elements at risk on a scale of 0 to 1.

Lec 10 Flood forecasting

Defn: Use of forecasted precipitation and streamflow data in rainfall-runoff and streamflow routing table to forecast discharge and water levels ranging from hrs to days.

Flood warning; making use of flood forecasted data to make decision as to whether to issue warning or retract prev one

Role of flood forecasting in flood management:

1. Save life, reduce damage: Provide critical lead time
2. Inform key authorities and disaster relief team for coordination.
3. Pre-disaster preparedness: Gives the time for emergency relief team to make out their contingency plan and mobilize support
4. Adjust dam release scheduling to ensure detention capacity.
5. Agricultural: Inform farmers to advance crop harvest

Data req:

1. Discharge
2. Rainfall
3. Topographic → contours

Lec 11 Types of damage

Intangible damage:

1. Direct damage: occuring from direct physical contact of flood (incl. debris) and goods, property, and/or struct.

   Direct urban damage: structures, building, contents, power plant
   Direct rural damage: crop, livestock, levee, capital equips (fences)

2. Indirect damage: Damages occuring indirectly during and after flood.

   Sales & production, earnings, transport disruption
   Cost of clean-up, relief, temp shelter
   Transport/moving of goods

Intangible damage: Damages classifiable more to social than economic.

E.g., personal time
inconvenience
health and psychology
risk

Approaches for economic evaluation:

→ Appropriate level of protection
→ optimal combination of measures

2. Cost / Benefit Analysis ; e.g., 50 yr levee → $10 m ; save $25 m
→ level of protection by benefit/cost appraisal ($B/C \geq 1$)

2. Fixed cost analysis ; e.g., city has $2 budget for relief
→ Project has pre-determined budgets.
Best protection that fixed money can buy

3. Cost effective analysis ; e.g., 100 yr airport defense
→ Project has preset level of protection
Budget is determined by evaluating combination of options meeting the set level.

4. Multi-objective approach ; e.g., multi-purpose reservoir
→ Cost alone doesn't play the key role ; others → social ben.
Project has multiple level of obj specified

5. Non-economic approach ; e.g., flood wall around religious monument
→ Governed by non-economic criteria
e.g., political
technical
social
env.

Lec 9 Cont.

$R = D \times H$; $H = \frac{1}{T}$

$D = EV$;

# Return Period (T, yr)	Damage (D, mTi)	D' (mTi)
10	8	4
20	15	7.5
50	35	26.25
100	70	70

$R = \Sigma DH$

$= \frac{8}{10} + \frac{15}{20} + \frac{35}{50} + \frac{70}{100}$

$= 2.95$ mTi/yr

$R' = \Sigma D'H$

$= 4/10 + 7.5/20 + \frac{26.25}{50} + \frac{70}{100}$

$= 2$ mTi/yr

$\therefore$ Benefit $= 2.95 - 2 = 0.95$ mTi/yr