Basic Basin Hydrology and Morphology for Flood and Drought management
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Outline of presentation

1. River Basin Hydrology
2. River Morphology and Sediment Transport
3. The Watercourse in Equilibrium
4. Fluvial Processes and the Shaping Of Rivers
5. Morphology of Natural Channels
6. Flood Frequency Analysis
**River Basin Hydrology**

**Introduction**

- Hydrology describes the occurrence, circulation, distribution, and chemical and physical properties of the earth's waters.
- A **drainage basin** is an extent or area of land where surface water from rain and melting snow or ice converges to a single point, usually the exit of the basin, where the waters join another water body, such as a river, lake, reservoir, estuary, wetland, sea, or ocean.
River Basin Hydrology

Shape of Drainage Basins
- Every basin has a unique shape. Horton (1932) proposed the form factor in order to express the shape of a basin quantitatively. The form factor (F) is defined as $F = \frac{B}{L}$, where $B$ and $L$ are the mean basin width and the maximum basin length, respectively.

Drainage Patterns
- A drainage map is a plan of all streams or river systems in a drainage basin. It presents some characteristics of drainage basins through drainage pattern and drainage texture.

Alluvial plain
- A plain formed by fluvial processes.
River Basin Hydrology

**Channel process:**
- Morphogenetic processes being carried out by running water in a channel. Main processes are erosion, transportation and sedimentation.

**Graded river**
- A river in which the gradient of the river bed does not vary, in this condition, erosion is in proportion to sedimentation.

**Rejuvenation**
- Renewal of former processes. Erosion is one of the fluvial processes reactivated.
River Morphology and Sediment Transport

- The term river morphology and its synonyms fluvial morphology are used to describe the shapes of river channels and how they change over time.
- Channel processes reflected in river morphology are erosion, transportation and sedimentation.
River Morphology and Sediment Transport

Sediment loads are classified into bed load and suspended load.

i. **Bed load**
   - The term **bed load** describes particles in a flowing fluid (usually water) that are transported along the bed consisting of material of larger diameter than fine sand, is brought to the lower reaches.
   - Bed load moves by rolling, sliding, and/or saltating (hopping).
River Morphology and Sediment Transport

ii. **Suspended load**

- **Suspended load** is the term for the sediment particles which settle slowly enough to be carried in flowing water (such as a stream or coastal area) either without touching the bed or while only intermittently touching it.
- These particles are generally of the fine sand, silt and clay size, although larger particles may be carried as well depending on the intensity of the flow.
River Morphology and Sediment Transport

Channel Processes

I. Erosion

- Running water carries out two processes. One is erosion and the other is corrosion.
- Erosion is a hydraulic action and is derived from the energy of running water. Gravel being brought by running water scours the channel and removes sediment from the river bed.
- Erosion makes a channel broader and deeper. These processes are also called lateral erosion and deepening erosion respectively.
II. Transportation

- The higher the water velocity, the more capacity a river has for transporting sediment load.
- There are three different processes in transporting sediment load. They are corrosion, suspension and traction.

- **Corrosion** is the process in which stream water corrodes rocks and brings them invisibly into solution.
River Morphology and Sediment Transport

- **suspension** is the process in which such fine materials as clay, silt, fine sand and materials lighter than water are transported in the water or on the water surface without contact with the river bed.

- **traction** is the process in which suspended load creates the turbidity of stream water, and gravel of larger diameter slides or rolls, and sand hops or bounds on a river bed.
River Morphology and Sediment Transport

III. Sedimentation

- A flood caused by heavy rain carries a huge volume of bed load from mountains to the plain.
- When a flood flows from the mountains to a plain, the capacity to transport bed load is suddenly reduced.
- Particles of bed load are deposited in order of their size, and an alluvial plain is formed.
The Watercourse in Equilibrium

- Natural streams are essentially open hydraulic systems in equilibrium.
- The variables are those that govern discharge and are: channel width, boundary roughness, size and concentration of sediment load and depth and slope.
- A change in any one of these interdependent variables must be compensated for by a change in the others.
Fluvial Processes and the Shaping Of Rivers

- Several natural factors govern the physical process in rivers and hence their morphology.
- As water works its way downstream, energy is expended on the transportation and rearrangement of materials in the river channel and on the flood plain.
  - Schumm (1977) assigned three zones to the land-water interactions within fluvial hydro systems:
ZONE 1: Sediment supply zone

- This is the upper zone within the catchment.
- This zone is characterized by valley slopes impinging almost directly onto the channel.
- There are coarse channel sediments and these arise from bank and slope erosion inputs.
Fluvial Processes and the Shaping Of Rivers

ZONE 2: Sediment transfer zone

- Comprises mainly the lowland reaches of the river where the channel is often bordered by a wide floodplain.
- In this zone the rivers redistributes sediment derived from upstream and bank and bed erosion.
Fluvial Processes and the Shaping Of Rivers

ZONE 3: Depositional zone

- Sediment is deposited in estuary.
- The range of substrates found within the ‘production’ and ‘transfer’ zones together with their hydrological regime, determine the habitat characteristics of the river.
Morphology of Natural Channels

- The full range of the plan geometry/pattern has never been identified: however, it includes straight, meandering and braided.
- Broadly speaking, meandering is characteristic of lowland rivers with slack slopes, and braiding is characteristic of steeper upland reaches.

i. **Straight Channels**
- Straight rivers are rare in nature. Meander patterns are often present in straight channels, since the thalweg is often found to swing from one side to another.
Morphology of Natural Channels

ii. Meandering Channels

- Meandering channels are single channels that are sinuous in plan.
- Meandering channels are efficient equilibrium features that represent the channel plan geometry, where single channels deviate from straightness.
- This deviation is related in part to the cohesiveness of channel banks and the abundance and bulk of midstream bars.
Morphology of Natural Channels

iii. **Braided Channels**
- Braiding is a feature of channels with steeper slopes, where flows have high energy.
- Braided channels are subdivided at normal flows by midstream bars of sand or gravel.
- At high water, many or all bars are submerged.
- A single meandering channel may convert to braiding where one or more bars are formed.
River Basin Hydrology

There are 12 major river basins in Ethiopia
# Features of Ethiopian River basins

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<th>Basin Name</th>
<th>Temperature (°C)</th>
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Ministry of Water Resources and Energy
River Basin Hydrology

- The topography of the country is rather rugged with distinctly defined watercourses.
- Large scale flooding is limited to the lowland flat parts of the country.
- Intense rainfall in the highlands causes flooding of settlements in a number of river basins.
- The level of the waters of some main lakes has been gradually increasing causing damage to infrastructure in many areas.
- The rainy season in many parts of the country extends for three to four months between June and September.
River Basin Hydrology

- Inundation of lands risk in some of the basin
  - Awash: 200,000-250,000 ha during high flows
  - Baro-Akobo Plain an area of about 300,000-350,000 ha is prone to annual flooding
  - Wabi-Shebelle Basin some 100,000 ha may be inundated

- The level of the waters of two main lakes (Awassa and Besseka) has been gradually increasing

- Flooding in 2006 and 2007 in Lake Tana which affects many households and farm lands

- Flood damages to settlements along their banks example the case of Dire Dawa, initiated by torrential rain during the rainy season
River Basin Hydrology

![Graph showing runoff (mm) from January to December. The graph indicates significant runoff peaks in August and September, with the Blue Nile at Kessie showing the highest peak. The legend includes Outflow from Lake Tana, Blue Nile at Kessie, Blue Nile at Rosieres, and Blue Nile at Khartoum.]
Water level variation of Rift lakes
Monthly Rainfall, Evaporation and Flow of the Upper Awash-Sub basin

Frequency Analysis

- Hydrologic systems are sometimes impacted by extreme events such as severe storms, floods, and droughts.

- The magnitude of an extreme event occurring less frequently than more moderate events.

- The objective of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions.
Frequency Analysis

The results of flood flow frequency analysis can be used for many engineering purposes;

1) for the design of dams, bridges, culvert, and flood control structures.
2) to determine the economic value of flood control projects.
3) to delineate flood plains.
4) to determine the effect of encroachments on the flood plain.
Frequency Analysis

The frequency of occurrence and probability of many climatological and hydrological data sets can be analyzed using statistical probability distributions.

The distribution of a set of data can be analyzed either by graph paper or mathematical computations.

The graph paper (probability distribution papers) allows answering such questions as:

- What is the probability of rainfall greater than the design capacity of my drainage network?
- If I want to design an embankment to hold backwater from a flood that happens say an average once every 50 years, how large a flood do I need to design for?
Frequency Analysis

- This is not simple and may have to be found by trial and error.
- The graphical method is a very good way to see how well the data set as a whole fits a distribution.

- **Normal distribution**: This distribution has no skew. The data is symmetrical around the mean.
- **Lognormal distribution**: This has a moderate skew and can be used to describe sets of flood peaks like annual series.
- **Gumbel (or “Extreme value type I”) distribution**: This also has a moderate skew.
- **Pearson 3 and log-Pearson 3 distributions**: These are more complex probability distributions that can deal with a wide range of skew.
Plotting Position

**Simple Formula:**
\[ P(X \geq x_m) = \frac{m}{n} \]

**Hazen’s Formula (1930):**
\[ P(X \geq x_m) = \frac{m - 0.5}{n} \]

**Chegodayev’s Formula:**
\[ P(X \geq x_m) = \frac{m - 0.3}{n + 0.4} \]

**Weibull’s Formula:**
\[ P(X \geq x_m) = \frac{m}{n + 1} \]

Where
- \( m \) = the rank of a value in a list ordered by descending magnitude
- \( n \) = the total number of values to be plotted
- \( x_m \) = the exceedence probability of the \( m \)th largest value
Suppose that an extreme event is defined to have occurred if a random variable $X$ is greater than or equal to some level $X_{Tr}$.

The probability of occurrence of an event (e.g. rainfall) whose magnitude is equal to or in excess of a specified magnitude $X_{Tr}$ is denoted by $P$.

The recurrence interval is the time between occurrences of $X \geq X_{Tr}$.
Return Period

- Thus, “the return period of an event of a given magnitude may be defined as the average recurrence interval between events equaling or exceeding a specified magnitude”.

- The probability of occurrence of the event $X \geq x_{Tr}$ in any observation is

$$p = P(X \geq x_{Tr})$$

$$T = \frac{p}{[1-(1-p)^N]} = \frac{1}{p}$$
Frequency Factors

- The magnitude $x_{tr}$ of a hydrologic event can be represented as the mean plus the departure $\Delta x_{tr}$ of the variate from the mean.

\[ X_{Tr} = \mu + \Delta X_{Tr} \quad \text{mean} \]

\[ X_{Tr} = \mu + K_{Tr} \sigma \quad \text{Departure} \]

\[ x_{Tr} = \bar{x} + K_{Tr} S_x \]

$K_{Tr} =$ Frequency Factor
[Population]
[Sample]