Chapter 12: Depth-Area-Duration Relationships

Introduction

In hydrologic analysis and design, especially for flood control and reservoir planning, it's essential to estimate the rainfall distribution not only in time but also in space. A storm does not deposit uniform rainfall over an entire area; therefore, the estimation of rainfall depth over a catchment area must consider its spatial variability. This brings into use the concept of **Depth-Area-Duration (DAD) relationships**.

DAD relationships provide a systematic method to estimate average rainfall over varying areas and durations from point rainfall measurements. These relationships are critical in **design storms**, **probable maximum precipitation (PMP)** studies, and **flood estimation**.

12.1 Concept of Depth-Area-Duration Relationships

The **Depth-Area-Duration (DAD) curve** expresses the relationship between:

- **Depth** of precipitation (in mm or cm),
- **Area** over which it falls (in km^2), and
- **Duration** of the storm (in hours or days).

It illustrates how **rainfall depth decreases with increasing area** for a given duration and vice versa.

This relationship is generally derived from **historical storm data**, which is analyzed to find average areal precipitation for different durations and areas.

12.2 Need and Importance

1. **Hydrologic design**: DAD curves are essential in the design of dams, reservoirs, spillways, storm sewers, and culverts.
2. **Flood estimation**: Used to determine the input for flood hydrograph analysis.
3. **Catchment analysis**: Helps in understanding the spatial distribution of precipitation in watersheds.
4. **Estimation of PMP**: Forms the basis for probable maximum flood (PMF) analysis.

12.3 General Characteristics of DAD Curves

The typical characteristics of DAD curves include:

- For a **fixed duration**, rainfall **depth decreases** as the **area increases**.
- For a **fixed area**, rainfall **depth increases** with **duration** up to a certain limit.
- The curves tend to **flatten out** for large areas or durations due to spatial and temporal averaging.

DAD curves are usually plotted on **log-log** or **semi-logarithmic** scales, with area on the x-axis and rainfall depth on the y-axis.

12.4 Derivation of DAD Curves

12.4.1 Data Requirements

To develop DAD relationships, the following are required:

- Storm event data (preferably from **extreme or major storms**)
- Rain gauge network across the region
- Time-series rainfall data at each gauge

12.4.2 Isohyetal Method

One of the most common methods for calculating areal average rainfall is the **Isohyetal method**, where:

- Isohyets (lines of equal rainfall) are drawn over the storm area.
- The area between isohyets is computed.
- The volume of rainfall is estimated and averaged over the area.

This gives average depths for sub-areas, which are then used to create cumulative depth-area-duration data points.

12.5 Empirical Formulation of DAD Relationships

Several empirical equations have been proposed to describe DAD relationships. One widely used form is:

$$P = P_0 e^{-kA}$$

Where:

- P = Average depth of precipitation over area A,
- P_0 = Maximum point rainfall (at zero area),
- k = Decay constant,

- A = Area (in km²).

Alternate formulations use **power-law** or **logarithmic** relationships, depending on region and data fit.

12.6 Factors Affecting DAD Relationships

1. **Topography**: Hilly or mountainous areas show more variation due to orographic effects.
2. **Storm type**: Convective storms (localized) show steeper DAD curves than frontal or cyclonic storms (widespread).
3. **Seasonality**: Monsoon storms may differ from post-monsoon cyclones in terms of spread and depth.
4. **Rainfall intensity**: High-intensity short-duration storms have sharper DAD gradients.
5. **Data density**: Sparse gauge networks may underestimate the actual depth-area variability.

12.7 Depth-Area-Duration Analysis Procedure

Step 1: Collect rainfall data from storm events of various durations.

Step 2: Plot isohyets on maps for each duration.

Step 3: Calculate average precipitation for areas using isohyetal or Thiessen methods.

Step 4: Tabulate depth vs area for different durations.

Step 5: Plot DAD curves on logarithmic scales.

Step 6: Fit appropriate equations and determine constants.

12.8 Use in Estimating Probable Maximum Precipitation (PMP)

DAD curves are particularly important in PMP estimation. The steps include:

- Selecting **extreme historical storms**.
- **Transposing** and **maximizing** the storm by moisture maximization.
- Using DAD curves to find spatial distribution of PMP.
- Applying PMP to hydrologic models to estimate PMF.

12.9 Regional DAD Studies in India

Some DAD analyses have been performed in India by the **India Meteorological Department (IMD)** and **Central Water Commission (CWC)** for different meteorological subdivisions, such as:

- Central India (e.g., Mahanadi Basin)
- Western Ghats
- North-East India (Assam, Meghalaya – high intensity, short duration storms)
- Peninsular India (cyclonic rainfall, broad coverage)

These studies help define **design storm characteristics** for dam safety, urban drainage, and flood forecasting.

12.10 Limitations of DAD Curves

- **Stationarity Assumption**: Assumes historical rainfall behavior will continue, which may not hold under climate change.
- **Data scarcity**: High-quality data from dense rain gauge networks is not always available.
- **Empirical nature**: DAD curves are not purely physical and may not capture dynamic atmospheric conditions.
- **Limited applicability**: Each DAD curve is valid only for the region and storm type for which it was developed.

12.11 Advanced Approaches and Modern Tools

With the advent of technology, newer methods have enhanced DAD analysis:

- **Radar-based rainfall estimation** for real-time areal rainfall measurement.
- **Remote sensing** and **satellite data** to capture large-scale storm dynamics.
- **Geographic Information Systems (GIS)** for spatial analysis.
- **Hydrologic modelling software** like HEC-HMS or SWAT for integration of DAD data into watershed models.

12.12 Applications in Engineering Design

DAD relationships are indispensable in:

- **Design storm development**
- **Reservoir inflow studies**

- **Urban flood risk modeling**
- **Culvert and bridge design**
- **Runoff estimation in ungauged basins**

They are a fundamental tool for engineers and hydrologists to estimate **spatially distributed precipitation input** in various water resources projects.
