Chapter 14: Probable Maximum Precipitation (PMP)

Introduction

Probable Maximum Precipitation (PMP) is a key concept in hydrological design, especially when the failure of a hydraulic structure such as a dam or spillway could lead to catastrophic consequences. PMP is defined as the greatest depth of precipitation for a given duration that is physically possible over a particular area at a certain time of year. This value is not based on historical precipitation data alone but incorporates meteorological maximization principles to reflect the most extreme storm event possible.

Understanding PMP is crucial for the safe design of reservoirs, flood protection systems, and other water infrastructure in order to prevent overtopping or failure during extreme weather events.

14.1 Definition and Significance of PMP

- **Definition**: PMP is the theoretically greatest amount of precipitation that is meteorologically possible for a specific location and time.
- **Significance**:
  - Used for hydrological safety design of critical structures (e.g., dams, nuclear plants).
  - Basis for determining the **Probable Maximum Flood (PMF)**.
  - Helps in evaluating the risk and performance of infrastructure under extreme conditions.
  - Ensures compliance with national and international safety standards.

14.2 Factors Influencing PMP

PMP estimation depends on a variety of meteorological and geographic conditions:

1. **Atmospheric Moisture Content**: The capacity of the atmosphere to hold moisture.
2. **Storm Efficiency**: How effectively atmospheric moisture is converted into precipitation.
3. **Topographic Features**: Mountains, valleys, and elevation changes affect orographic lifting.

4. **Storm Path and Duration**: The trajectory and longevity of storm systems.
5. **Temperature**: Impacts both evaporation and the type of precipitation (e.g., snow or rain).

14.3 Estimation of PMP

There are primarily three methods used to estimate PMP:

14.3.1 Statistical Method (Empirical Method)

- Based on historical rainfall records and extreme value analysis.
- Limited to regions with long and reliable rainfall data.
- Uses frequency analysis to extrapolate extreme precipitation values.
- **Limitations**: Assumes past maximum events can predict future extremes, which may not be sufficient for PMP estimation.

14.3.2 Hydrometeorological Method

- **Moisture Maximization Approach**:
  - Based on actual storm events but scaled up using higher moisture content.
  - Uses the formula:

$$\text{PMP} = \text{P} \times \frac{\text{PW}_{\text{max}}}{\text{PW}_{\text{storm}}}$$

- Where:
  - P = observed precipitation
  - PW_{max} = maximum precipitable water at location
  - PW_{storm} = precipitable water during the storm event
- **Transposition Technique**:
  - Involves applying the characteristics of extreme storms from one region to another.
  - Storm data from areas with more extreme weather is "transposed" geographically.
- **Envelopment Curve Method**:
  - Uses upper limits of rainfall from multiple storms across regions.
  - Draws envelope curves representing maximum limits for different durations and areas.

14.3.3 Numerical Weather Modelling

- Advanced method using mesoscale meteorological models.
- Simulates extreme storm events by inputting boundary conditions with maximum moisture.
- Requires supercomputing and expert input.
- Still under research and development in many countries.

14.4 PMP Estimation for Different Durations and Areas

- PMP estimates vary with:
  - **Duration**: 1-hour, 6-hour, 24-hour, 3-day, etc.
  - **Area Size**: Smaller areas generally produce higher PMP values due to more intense rainfall.
- The **depth-area-duration (DAD)** relationships are used to express PMP values.
  - Helps in understanding how storm depth decreases with increasing area and time.
  - Used for regional PMP estimation.

14.5 Applications of PMP

- **Design of Dams and Spillways**:
  - Critical for setting spillway capacity to prevent overtopping.
- **Flood Hazard Mapping and Risk Assessment**:
  - Establishes PMF for emergency preparedness.
- **Urban Drainage Systems**:
  - Helps in designing for rare, high-intensity events.
- **Nuclear Facility Safety Design**:
  - Ensures cooling and containment systems are protected under extreme rainfall.

14.6 Limitations and Challenges in PMP Estimation

- **Data Availability**: Lack of high-quality rainfall and moisture data, especially in remote regions.

- **Assumptions in Maximization**: Meteorological assumptions may not hold under future climate conditions.
- **Transposition Errors**: Applying storms from one region to another may lead to inaccuracies.
- **Climate Change Uncertainty**: Future PMP may be different due to changing atmospheric moisture capacity.

14.7 PMP and Climate Change

- Warming climate leads to increased moisture-holding capacity in the atmosphere (as per Clausius-Clapeyron relation).
- Potential increase in extreme precipitation events globally.
- Current PMP values may need revision under future climate scenarios.
- Use of Regional Climate Models (RCMs) and Global Climate Models (GCMs) is being explored to project future PMP values.

14.8 Guidelines and Standards for PMP Estimation

- **India**:
  - Central Water Commission (CWC) and India Meteorological Department (IMD) provide PMP atlases and estimation protocols.
- **International**:
  - World Meteorological Organization (WMO) publishes guidelines on PMP estimation.
  - United States Bureau of Reclamation and National Weather Service (NWS) offer region-specific PMP values and design criteria.

14.9 Case Studies and PMP Atlases

- **India PMP Atlases**:
  - Prepared by IMD and CWC for various river basins.
  - Include maximum observed rainfall and estimated PMP contours for 1-day and 3-day durations.
- **Notable Case Study**: Bhakra Dam and Tehri Dam have design floods based on PMP-based PMF.
- **International Cases**: Oroville Dam (USA), Snowy Mountains Scheme (Australia), Three Gorges Dam (China).
