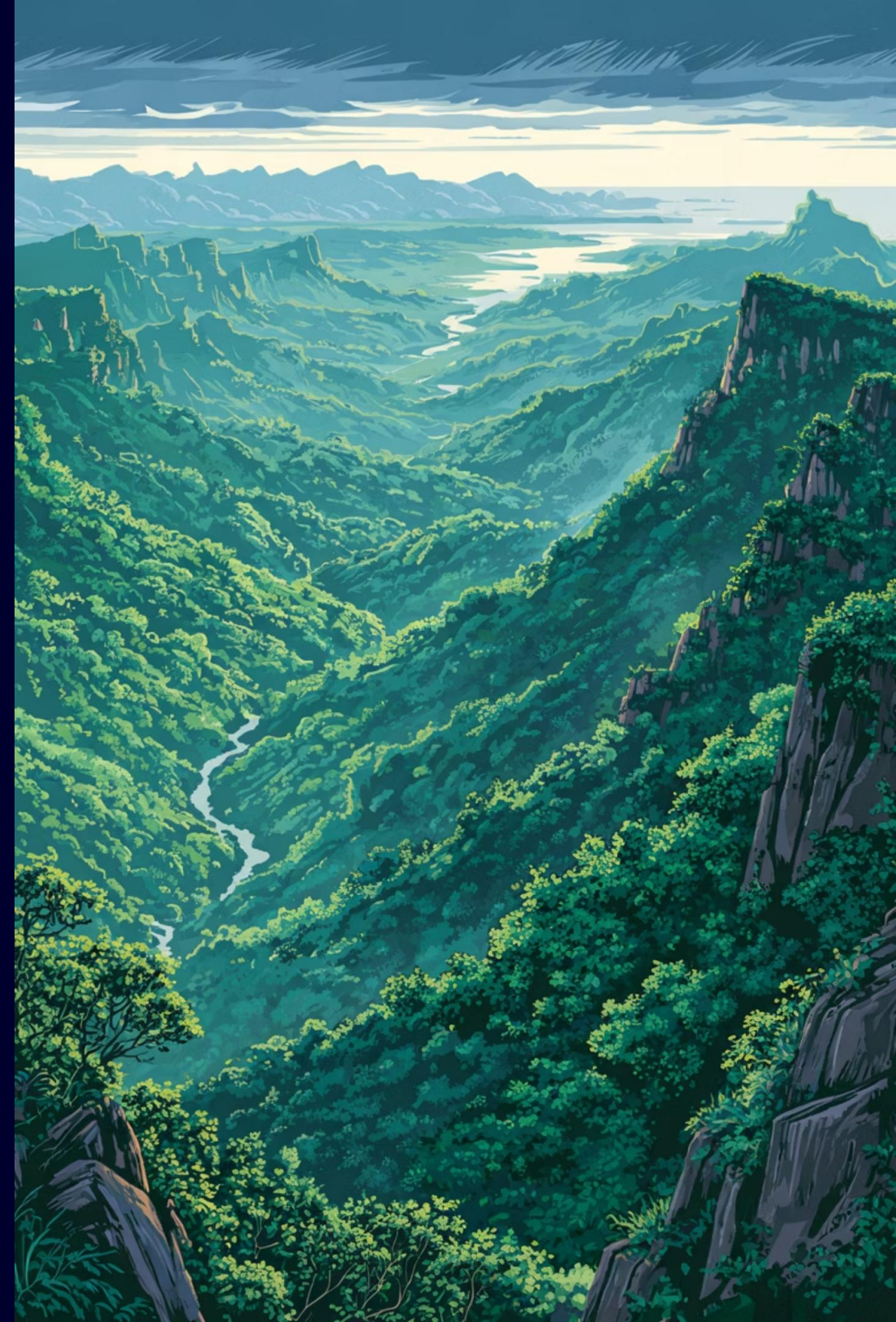


Design Flood Revisions & Spillway Adequacy in Steep Tropical Catchments

A multi-dam reassessment from Kerala, India, examining how PMP-based flood estimates reveal widespread spillway inadequacy

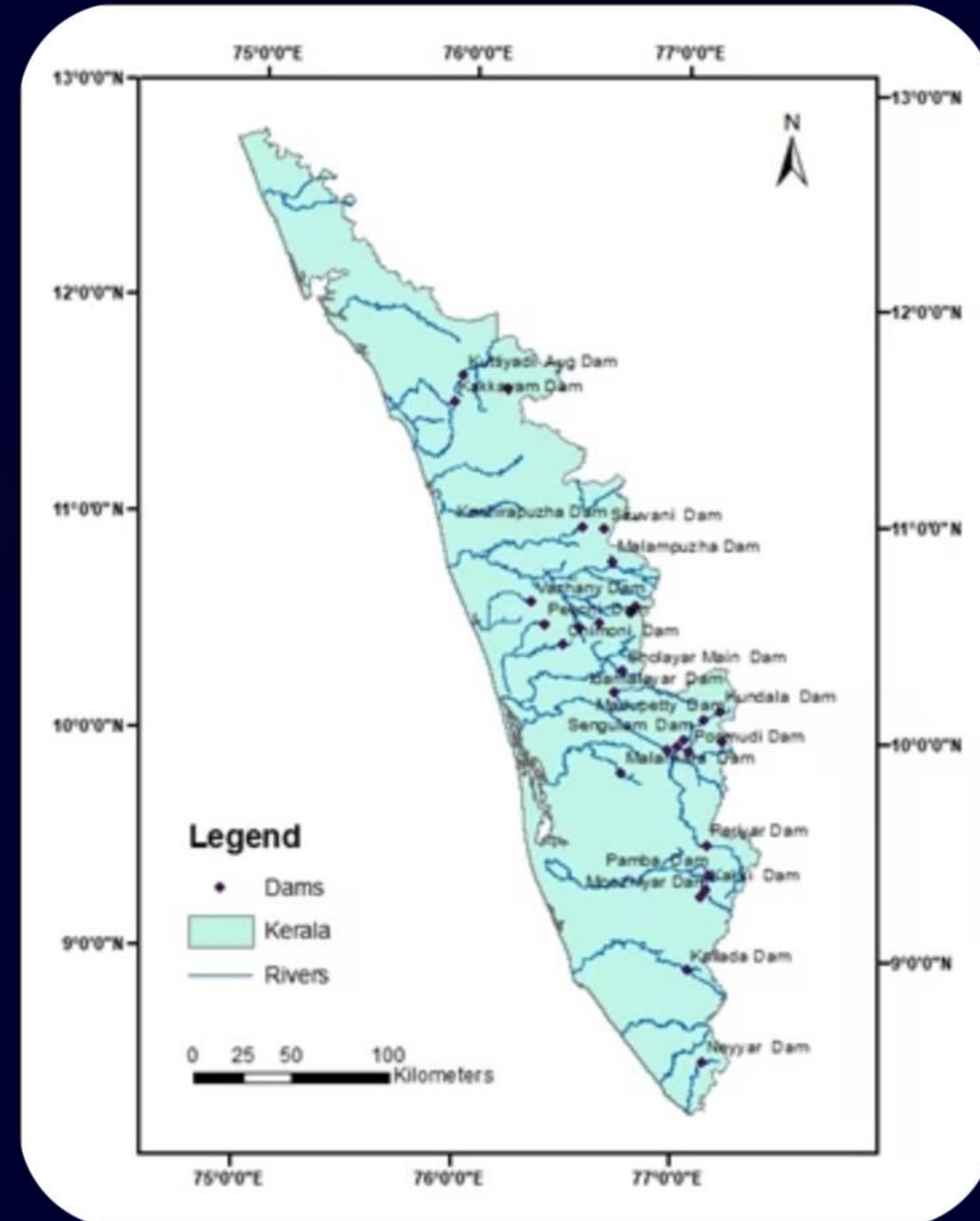
Presented by: Isly Issac

Session NH1.3 - Hydrologic Extremes: Spatiotemporal Evolution, Cascading Impacts, and Adaptive Resilience

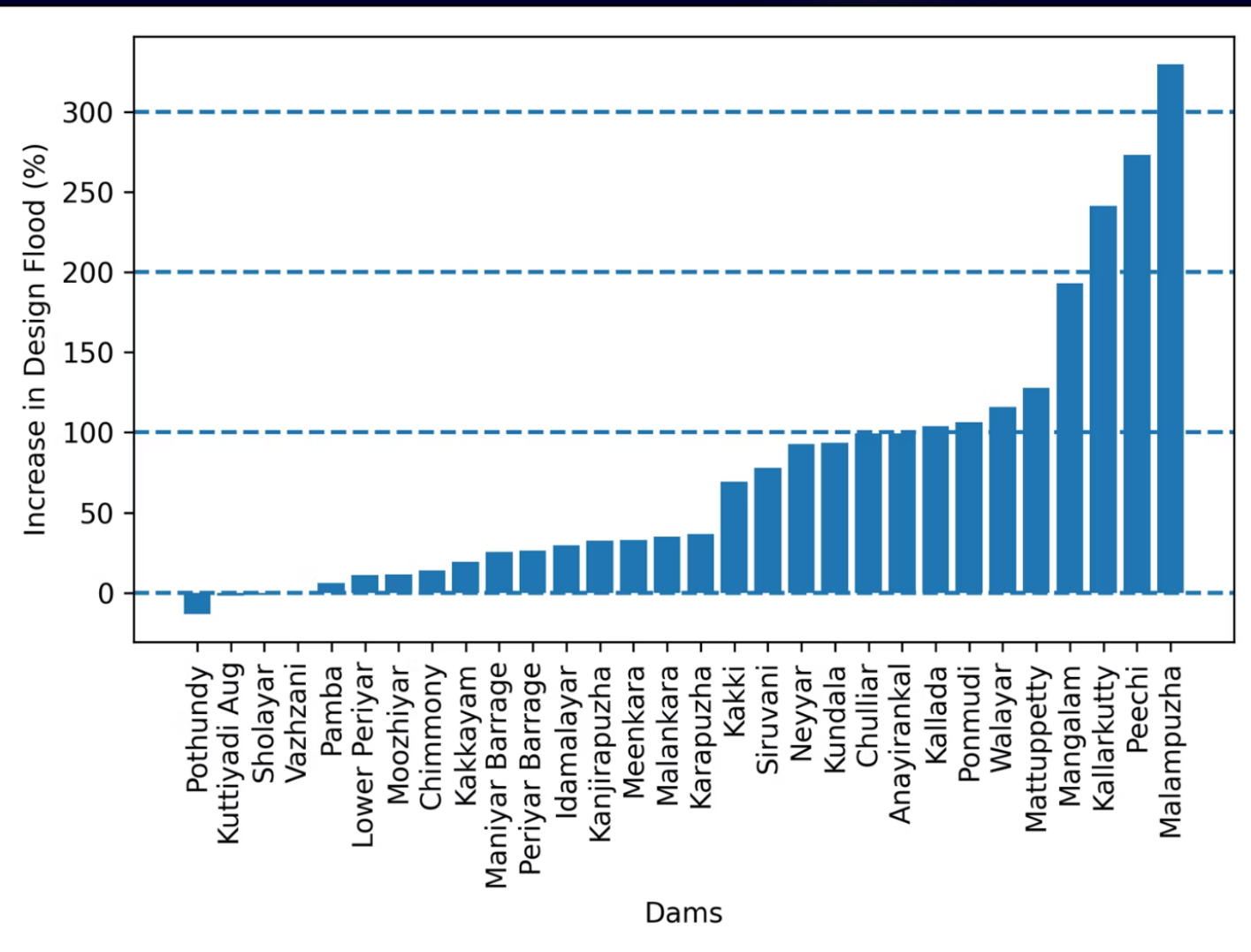


Kerala Flood Risk Context

- Kerala receives ~3,000 mm/year of rainfall across steep terrain, producing time-of-concentration values as short as 0.7–5 hours.
- Dense populations and cascade dam systems compound the hazard.
- The 2018 floods exposed critical vulnerabilities – most dam spillways were designed under outdated flood standards that no longer reflect current PMP estimates.



Methods & Key Findings

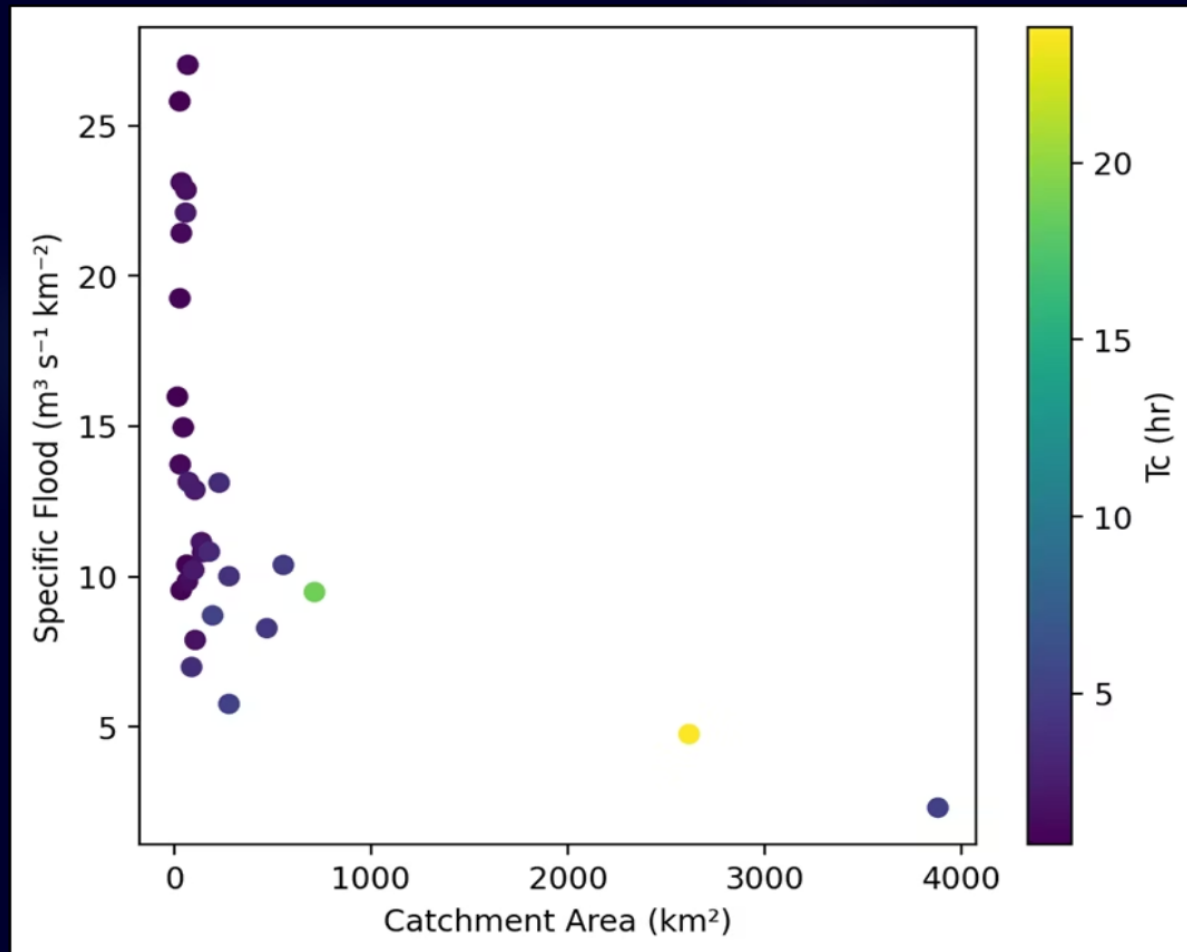


Flood estimates derived using **PMP-based analysis per IS 11223**, integrating the India PMP Atlas with DEM-based hydrological modeling to reassess inflow design floods across 30 dams.

- **26 of 30 dams** have spillways inadequate for updated PMP-based floods
- Flood magnitudes increased an average of **+76%**, with peaks up to **+300%**
- Small basins exhibit the **highest flood intensity** due to rapid concentration

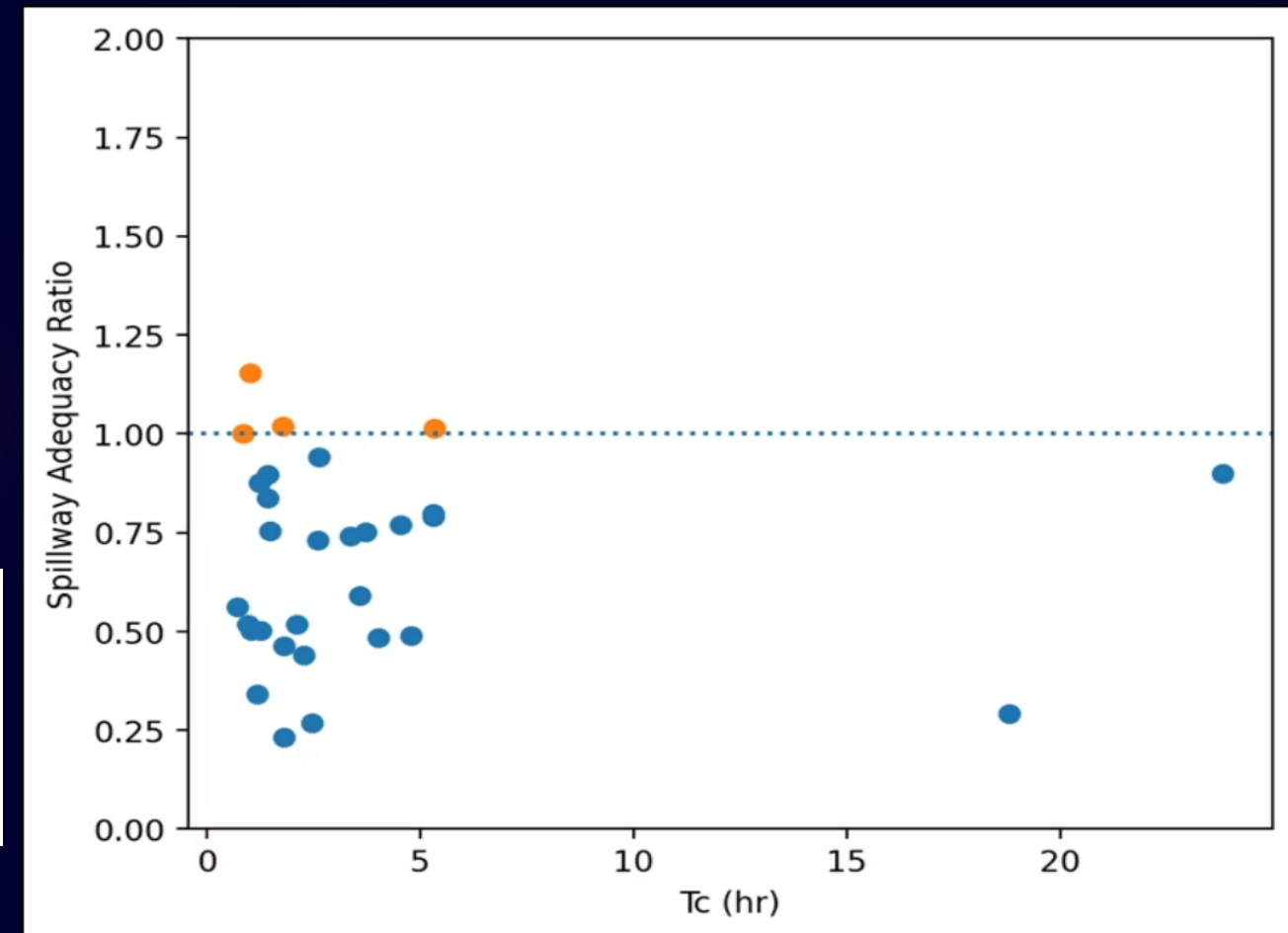


Flood Intensity and Spillway Vulnerability in Steep Tropical Catchments in Kerala, India



Specific flood vs C.A

Smaller, steeper catchments produce disproportionately higher flood intensity, showing flash-flood dominance



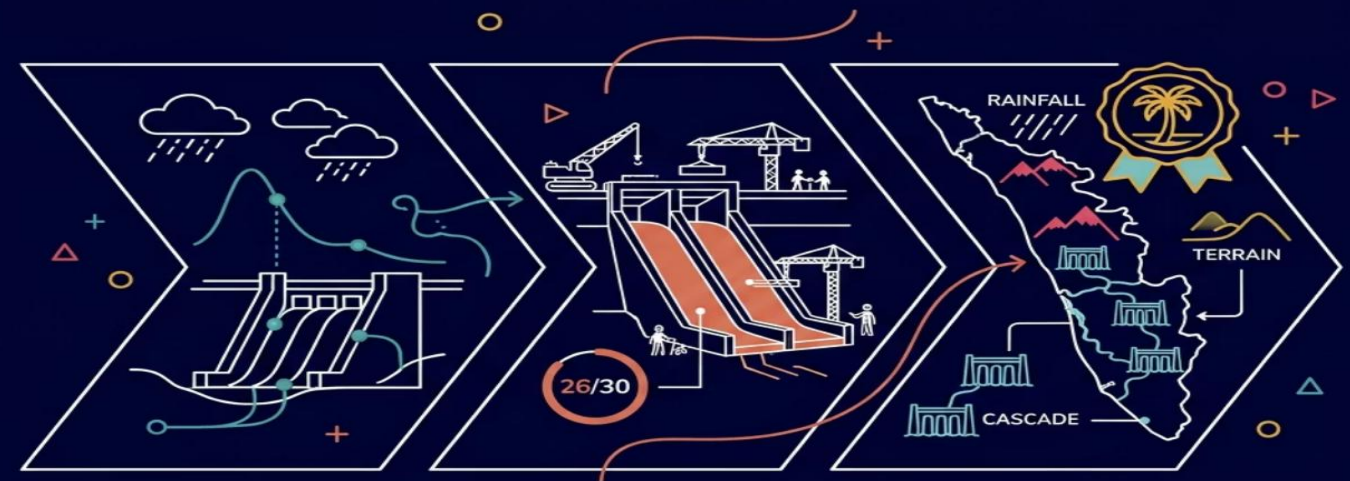
Spillway adequacy ratio vs T_c

Dams with shorter response times have lower spillway adequacy, making them more vulnerable to extreme floods.

Implications & Conclusion

Why Flood Risk Is Amplified

- Short Tc basins generate **rapid, intense flood peaks** with minimal warning
- **Cascade dam configurations** amplify downstream risk through sequential releases
- Most dams are **structurally unsafe** under revised PMP-based inflow design floods



- 1) PMP-Based Redesign for reassessing spillway adequacy and inflow design of all dams
- 2) Spillway Upgrades for 26/30 dams
- 3) Regional Standards-Develop Kerala-specific flood design criteria reflecting storms, terrain and cascade dam dynamics.



Why Kerala Is Hydrologically Critical

~3,000 mm/yr Average Rainfall

Orographic precipitation from the southwest monsoon on the windward Western Ghats flank

859 persons/km²

High population density; settlements are concentrated in river valleys downstream of reservoirs

53 Large Dams

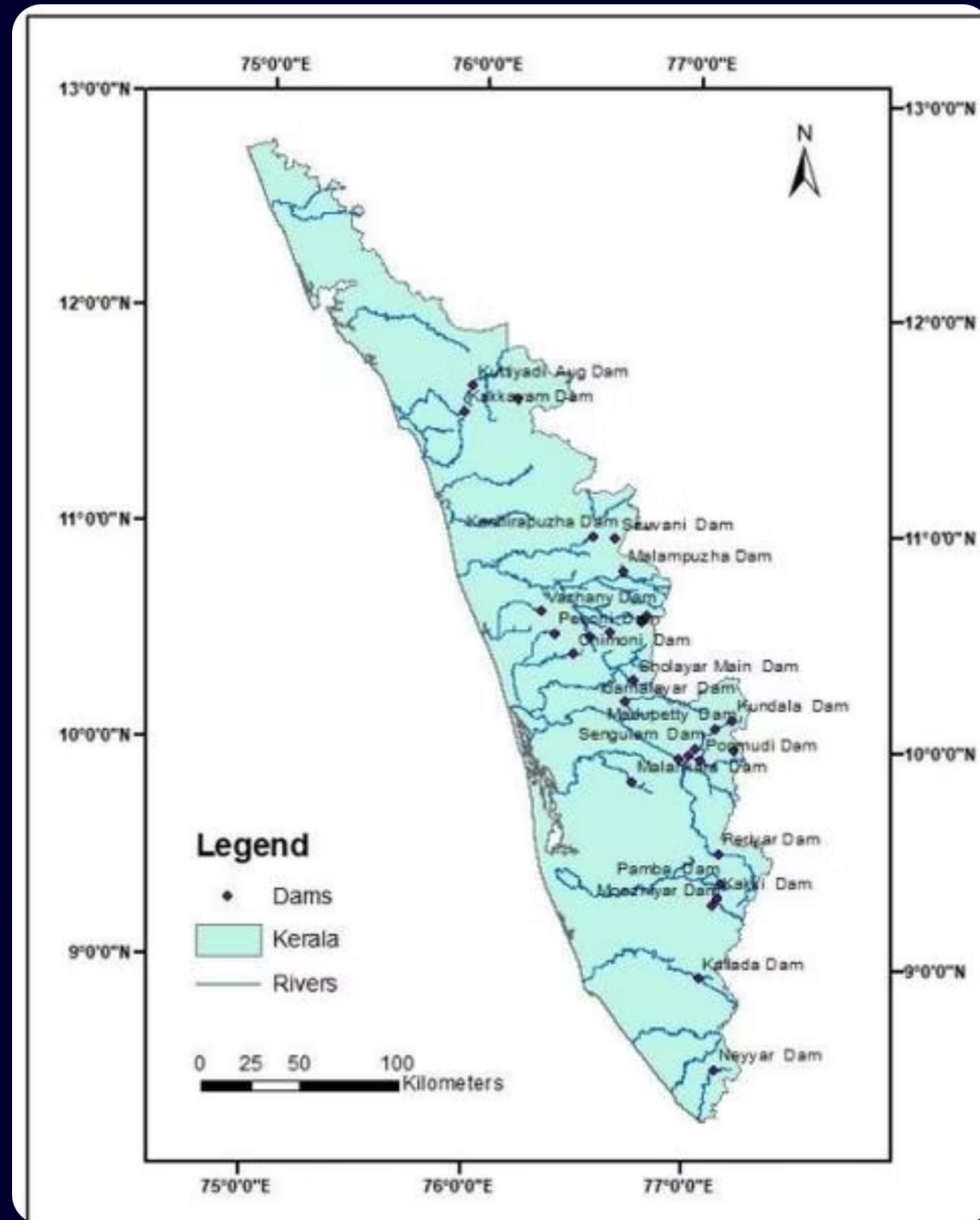
30 dams across 9 basins were analysed; many are in cascade arrangements within 100 km of the Arabian Sea

2018 Catastrophic Floods

These emphasised the urgent need for updated IDF reassessment and spillway performance review



Study Area: Steep, Fast-Responding Basins



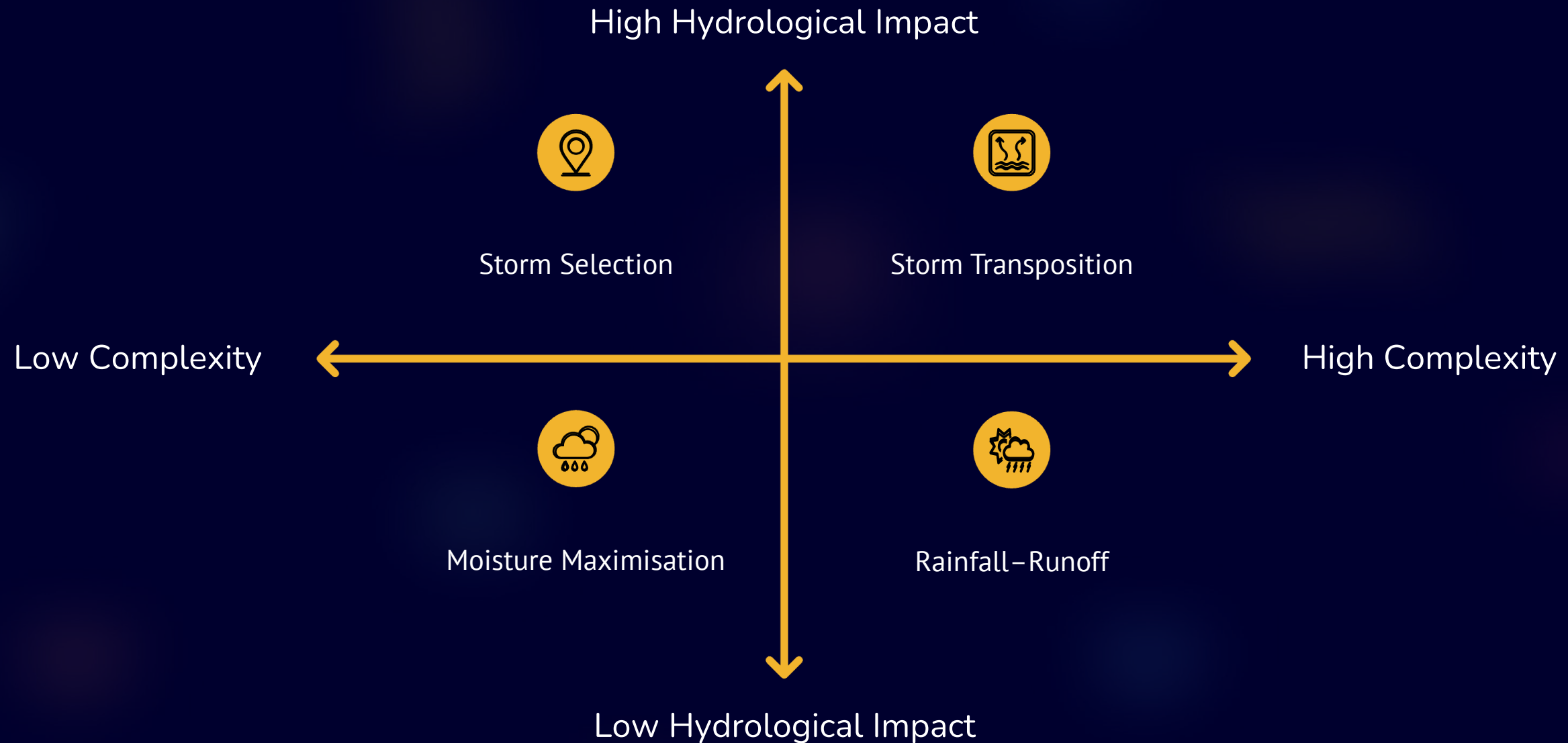
Catchment Characteristics

- Catchment areas: 18 to 3,878 km²
- Longitudinal slopes: 20–52 m/km
- Time of concentration (T_c): 0.7 to 5 hours
- Specific flood discharge: up to 13 m³ s⁻¹ km⁻²

The Western Ghats rise from sea level to ~2,500 m within 80 km, producing intense orographic rainfall, flash-flood-type responses, and minimal natural attenuation.



Methodology: PMP-Based Framework



Following **IS 11223:1985**, design floods were derived using the CWC-IMD PMP Atlas (2015), storm transposition, moisture maximisation, and FER-based synthetic unit hydrographs calibrated for Western Ghats catchments.



Three Dominant PMP-Control Storms

Analysis of the PMP Atlas reveals three historical extreme storms that control PMP-scale rainfall across all 30 dams:

1

Devikulam Storm — 17 July
1924

484 mm at storm centre; MMF =
1.07

2

Bhagamandala Storm — 25
July 1924

842 mm – highest recorded; MMF =
1.29

3

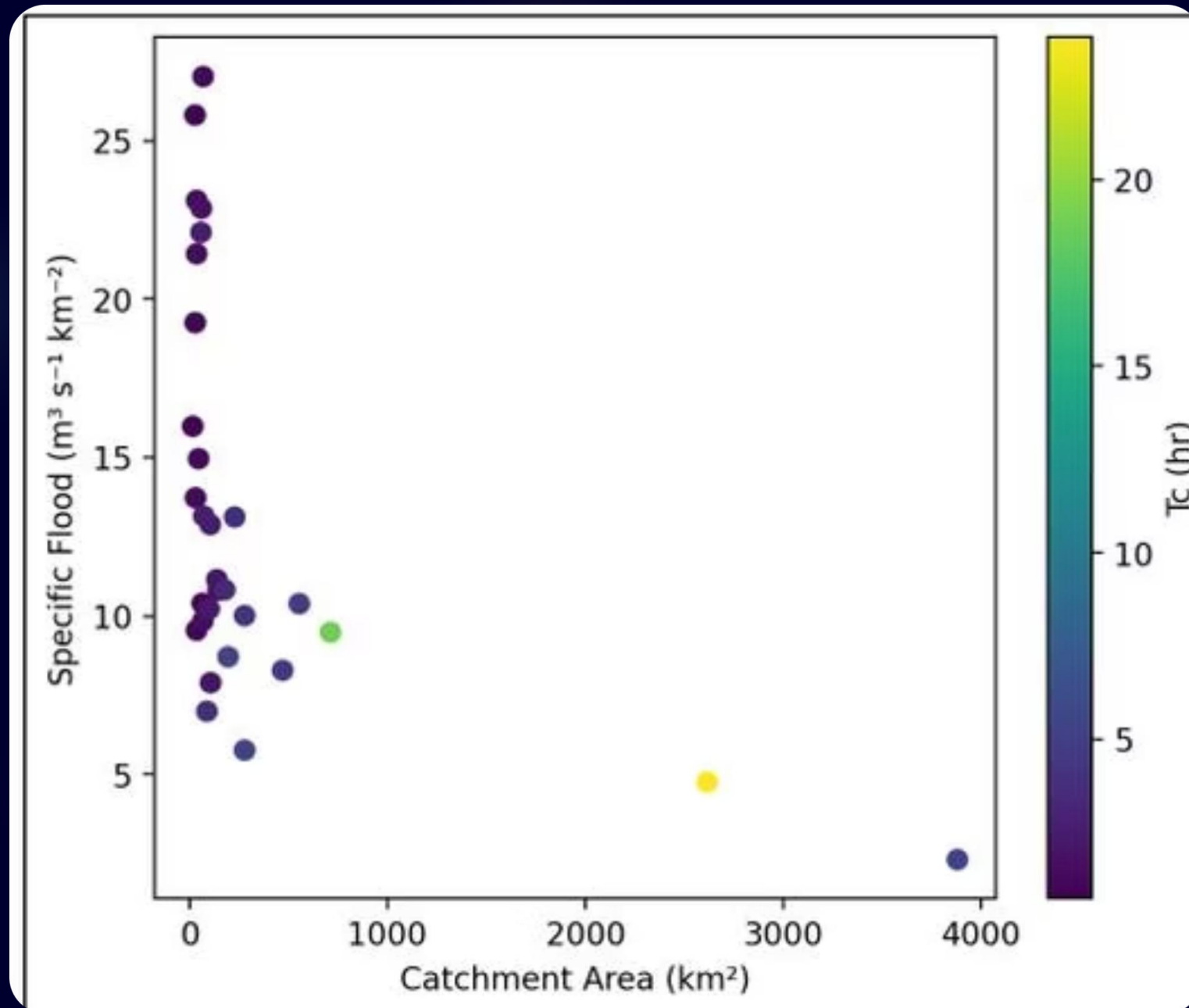
Ponmudi Storm — 18
October 1964

406 mm; MMF = **1.29**

All three originated as intense Arabian Sea monsoon systems and remain unsurpassed in combined rainfall magnitude and areal coverage across Kerala.



Specific Flood vs Catchment Area



$$\text{Specific Flood} = \frac{\text{Peak flood discharge}}{\text{Catchment area}}$$

Three Hydrologic Regimes

Small (<100 km²)

Specific floods up to $25 \text{ m}^3 \text{ s}^{-1} \text{ km}^{-2}$;
Flash-flood-dominated response.

Medium (100–500 km²)

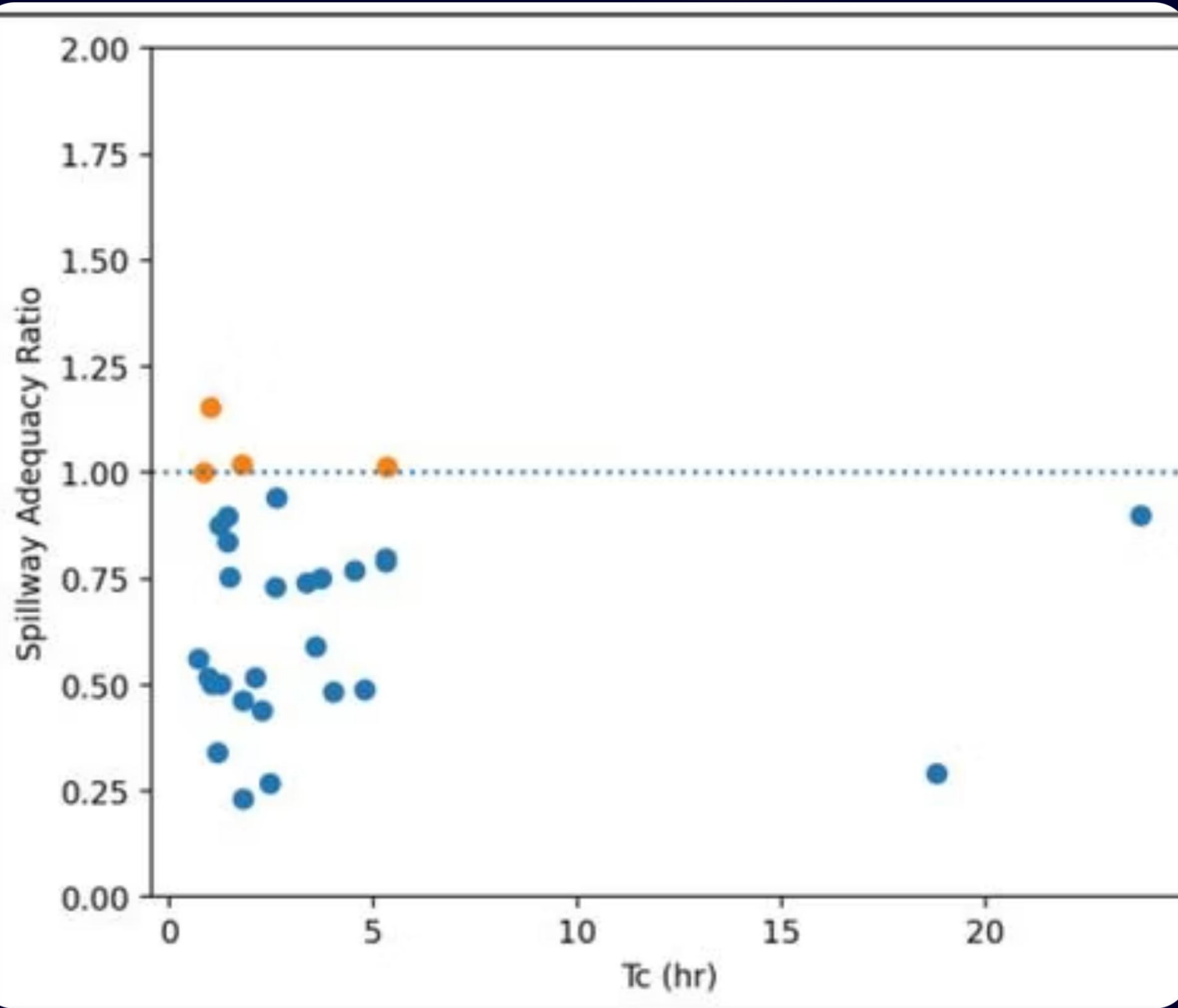
Partial attenuation, but still large peaks;
highest mean flood amplification.

Large (>500 km²)

Lower specific floods,
yet absolute inflows remain very high.



Spillway Inadequacy: The Core Finding



$$\text{Spillway Adequacy Ratio (AR)} = \frac{\text{Original DF}}{\text{Revised DF}}$$

AR \geq 1 Adequate spillway capacity

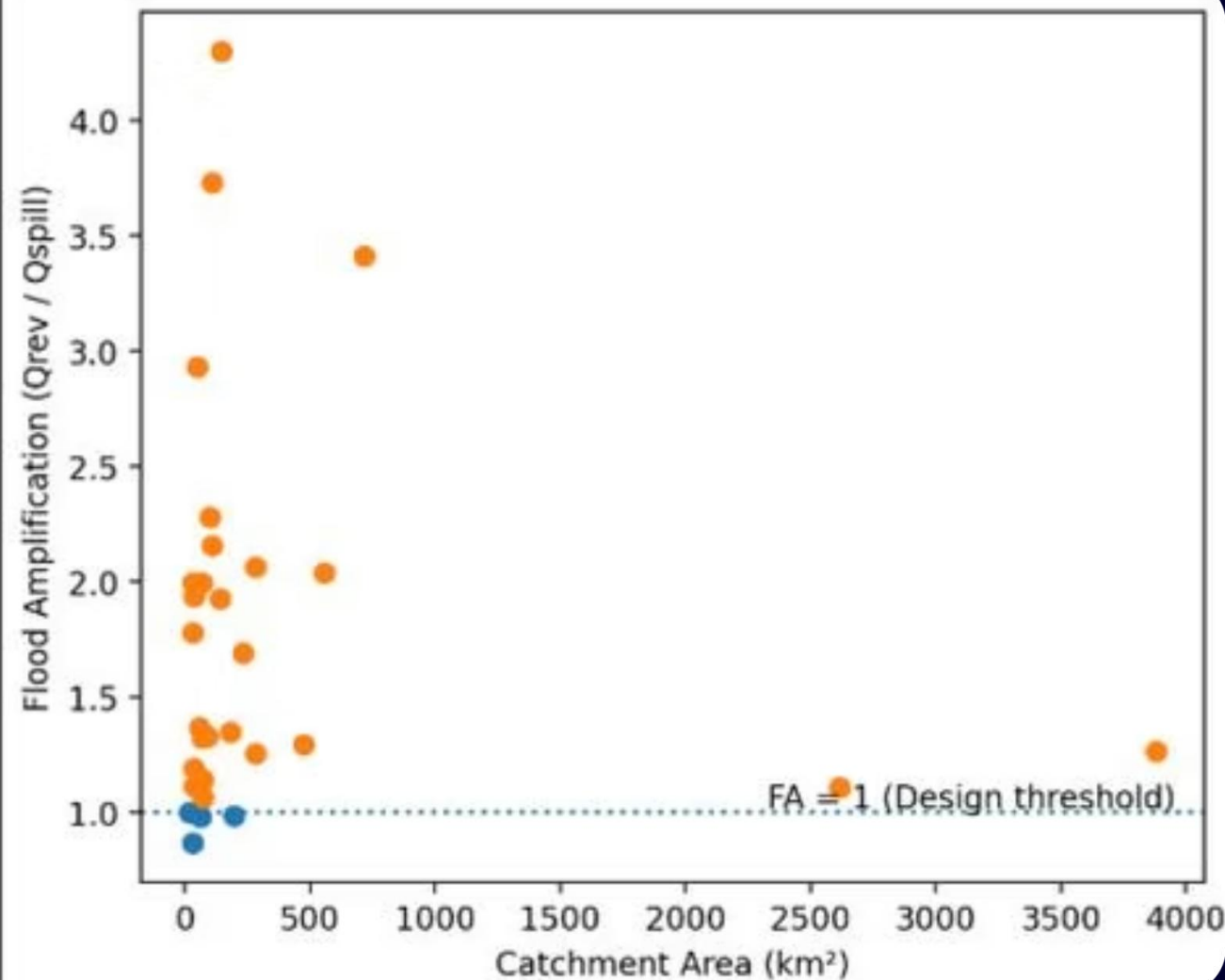
AR < 1 Spillway Inadequate

26 of 30 dams have AR < 1 – spillways cannot safely pass revised PMP-based floods.

- Exceedance is frequently **>200%**, and in some cases **>300%**
- Shorter T_c \rightarrow lower AR \rightarrow greater vulnerability
- Most severe in short-response, high-specific-flood catchments



Flood Amplification Across Dams



$$\text{Flood Amplification (FA)} = \frac{\text{Revised Design Flood}}{\text{Original Design Flood}}$$

FA >1 means the revised design flood is exceeded
Highest amplification occurs in small, steep basins.
FA remains >1 even in large basins—an increased area alone does not eliminate the hazard.

Median Increase

~36%

Mean Increase

~76%

Max Increase

+330% (Malampuzha)



FA-Based Safety Classification

FA Range	Dams	Mean Tc (h)	Class
0–1	4	2.25	Adequate
1–1.5	12	4.74	Marginal
1.5–2.5	10	2.26	Unsafe
2.5–5	4	6.06	Critical

Catchment-Class Synthesis

Class	Dams	Mean Tc	Mean FA	Mean AR
Small (<100 km ²)	15	1.56 h	1.32	0.82
Medium (100–500)	11	3.42 h	2.09	0.57
Large (>500 km ²)	4	12.99 h	1.96	0.62

Unsafe and critical dams (FA > 1.5) = **14 of 30**

Medium catchments show the highest mean FA and the lowest AR

Short-response catchments are particularly vulnerable.



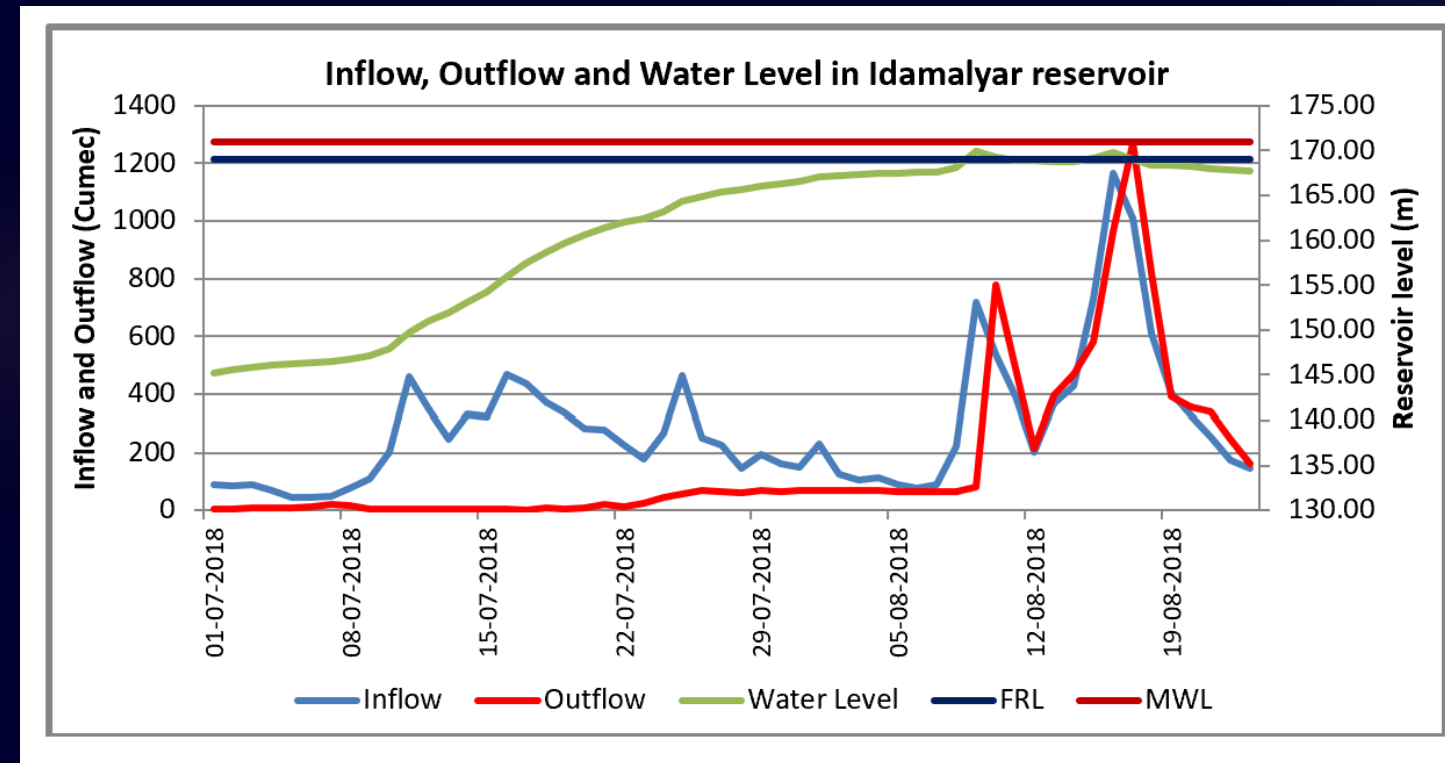
Kerala Floods 2018

Extreme Hydrological Event

- 800 mm rainfall in 3 days (Aug 15–17, 2018)
- Generated massive inflows exceeding the dam capacity

Reservoir Status Before Flood

- Most dams near Full Reservoir Level (FRL)
- Very limited flood cushion (<10%)
- Storage insufficient vs inflow
- Dams had limited ability to absorb floodwaters due to pre-filled conditions



Conclusions & Implications

→ Widespread Under-Design

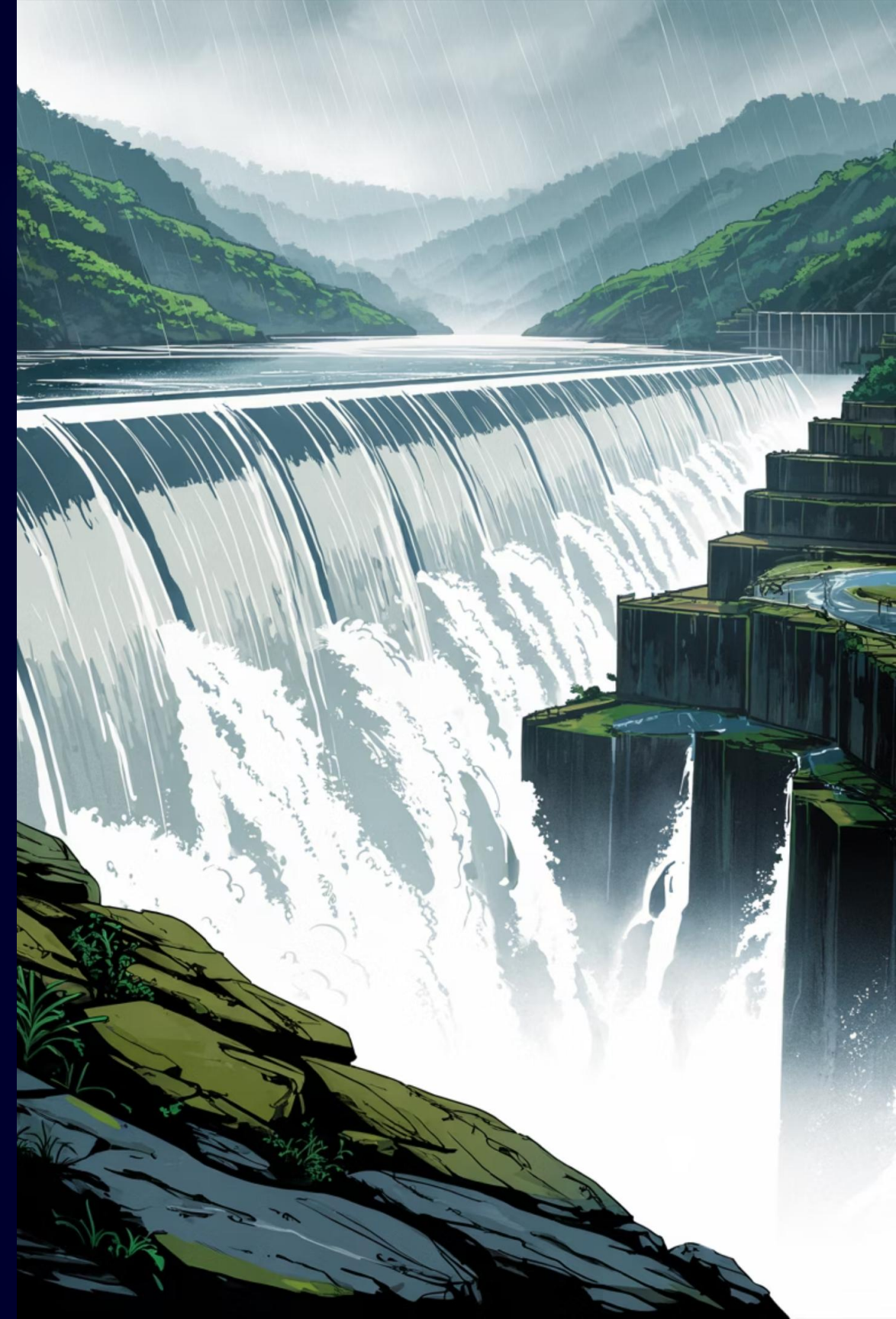
26 of 30 dams are spillway-inadequate under revised PMP floods; median increase of ~36%, mean of ~76%, range of 13% to +330%.

→ Region-Specific Criteria Needed

Traditional temperate-region hydrologic assumptions underestimate extreme floods in steep tropical basins. T_c , orographic rainfall, and rapid response must drive spillway design in the Western Ghats.

→ Cascade Risk

Many dams are in cascade systems; simultaneous spilling under PMP storms amplifies downstream flood risk – upstream adequacy is critical for basin-wide safety.



Thank You

