

EVALUATING PROBABILITY DISTRIBUTIONS FOR DESIGN RAINFALL ESTIMATION AND THEIR IMPLICATIONS FOR SPILLWAY DESIGN AT THE KALANKUTTIYA RESERVOIR, MAHAWELI SYSTEM H, SRI LANKA

A.R.L.S. Alahakoon^{1*}, N. Wijayaratna¹, L. Gunawardhana¹

¹ UMCSAWM, Department of Civil Engineering, University of Moratuwa, Sri Lanka

**Corresponding author: alahakoonarls.26@uom.lk*

Abstract

The design of hydraulic structures depends critically on the design flood, which is governed by the choice of probability distribution used to estimate extreme design rainfall. This study evaluates how distribution and estimation method affect design rainfall, design flood, and spillway capacity for the Kalankuttiya Reservoir catchment, Mahaweli System H, Sri Lanka. The Siyambalangamuwa station's annual maximum daily rainfall for 31 years was fitted to six distributions: Gumbel, Generalised Extreme Value, Log-Pearson Type III, Lognormal, Gamma, and Weibull. Anderson-Darling, Kolmogorov-Smirnov, and Chi-square tests were used to evaluate goodness-of-fit. The tail-sensitive Anderson-Darling statistic indicated that Log-Pearson Type III was the best-performing distribution. Design rainfall at the 50-year return period was estimated for each distribution and used to generate design flood hydrographs in a HEC-HMS model. Resulting peak discharge ranged from 230.8 to 293.1 m³/s, corresponding to a required spillway length of 45 to 59 m, a spread of approximately 24 and 27 percent, respectively. Critically, independent of distribution selection, all six distributions show a necessary spillway length that is significantly longer than the current 18 m spillway, indicating a significant capacity deficiency. Log-Pearson Type III is recommended as the primary design basis, with the full distributional range reported as an uncertainty envelope to inform urgent spillway capacity review.

Keywords: Design rainfall, Flood frequency analysis, Probability distributions, HEC-HMS, Spillway capacity

1. Introduction

Reliable estimation of the design flood is essential for safe spillway design, as the spillway is the main protection against dam overtopping and downstream flooding. Design floods are estimated by fitting a probability distribution to observed extreme rainfall data and estimating rainfall for the required return period [2]. However, no single distribution is suitable for all cases, and different distributions fitted to the same data can produce significantly different design rainfall and spillway requirements [1]. This uncertainty is often overlooked when a distribution is selected without proper justification. The Kalankuttiya Reservoir, located in Mahaweli System H, Galnewa DS, Anuradhapura District, has a 53 km² catchment and provides water mainly for irrigation and other downstream needs. The existing spillway is 18 m long. The objective of this study is to identify the most suitable probability distribution for estimating design rainfall in the Kalankuttiya catchment by evaluating six probability distributions using formal goodness-of-fit tests, and to assess the associated uncertainty in the 50-year design flood peak discharge and required spillway length.

2. Methodology

Annual maximum daily rainfall from 1985 to 2015 at the Siyambalangamuwa station, gap-filled using the neighbouring Kalawewa_dam station, was fitted to six distributions: Gumbel, Generalised Extreme Value (GEV), Log-Pearson Type III, Lognormal, Gamma, and Weibull. Gumbel, Lognormal, Gamma, and Log-Pearson III parameters were estimated by the method of moments (frequency-factor approach), consistent with Bulletin 17C practice [3]; GEV and Weibull were estimated by maximum likelihood. Goodness-of-fit was evaluated using the Anderson-Darling (AD), Kolmogorov-Smirnov (KS), and Chi-square tests [2]; the tail-sensitive AD test was prioritised for distribution selection given its relevance to extreme design events.

The 50-year return period was used as the design limit for this study, and the design rainfall was estimated for each distribution. Design flood hydrographs were produced by feeding the generated design storms into a HEC-HMS rainfall-runoff model developed for the Kalankuttiya Basin. River discharge from each hydrograph was routed through the reservoir to determine the spillway length required to safely convey the design flood, directly measuring how distributional choice propagates into spillway capacity uncertainty.

3. Results and Discussion

All six distributions gave statistically acceptable fits ($p > 0.05$, all tests), reflecting the limited power of a 31-year time series to discriminate between candidates (Table 1). Log-Pearson III recorded the lowest Anderson-Darling statistic (0.278), narrowly ahead of Gamma (0.279), and was adopted as the primary design distribution; Gumbel and Lognormal performed best on the less tail-sensitive KS and Chi-square tests.

Table 1: Goodness-of-fit test results for six candidate distributions.

Distribution	KSD	AD statistic	Chi ²	Avg. Rank
Log-Pearson III	0.098	0.278	2.371	2.67
Gamma	0.087	0.279	2.384	2.33
Gumbel	0.091	0.297	2.366	2.33
Lognormal	0.093	0.302	2.309	2.67
GEV	0.114	0.321	2.605	5.00
Weibull	0.120	0.647	3.907	6.00

Figure 1 shows design rainfall by distribution across return periods 2–200 years. All distributions converge below 10 years but diverge substantially at longer return periods relevant to spillway design, with Weibull and GEV trending highest and Gamma and Lognormal lowest.

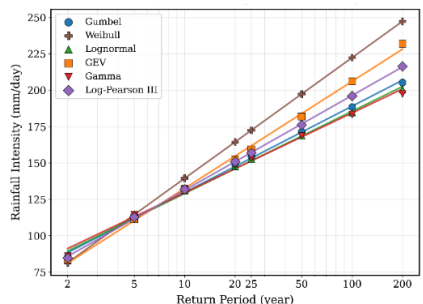


Figure 1: Design rainfall intensity vs return period.

Figure 2 presents the $T = 50$ -year design flood and spillway results. Peak discharge ranged from 230.8 m^3/s (Gamma) to 293.1 m^3/s (Weibull), and required spillway length from 45 to 59 m, a spread of $\sim 24\%$ and $\sim 27\%$ of the mean, respectively. Using Log-Pearson III, required spillway length is 52 m. Furthermore, all six distributions show a capacity deficit of 27–41 m, regardless of which distribution is chosen. This finding is robust to distributional uncertainty and indicates an urgent need for spillway capacity review at Kalankuttiya because the current spillway is only 18 m long.

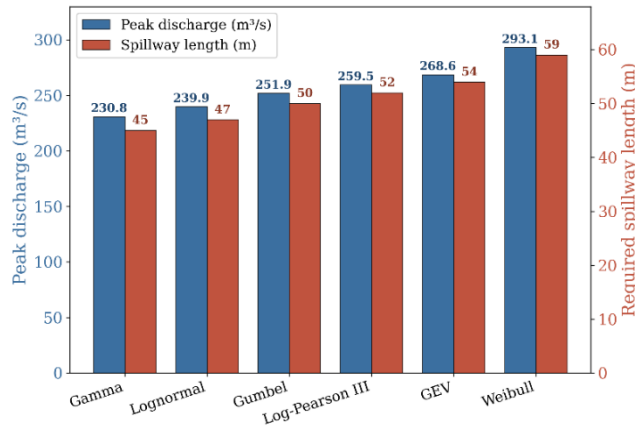


Figure 2: Peak discharge and required spillway length by distribution.

4. Conclusion

For the Kalankuttiya catchment, the choice of distribution was a major, measurable source of uncertainty in the design flood and spillway capacity, resulting in a 24–27% variation in peak discharge and spillway length at $T = 50$ years. More critically, the existing 18 m spillway falls short of the required 45–59 m under every distribution tested, indicating a capacity deficit that is robust to distributional uncertainty and warrants urgent engineering attention regardless of which distribution is ultimately adopted. Log-Pearson III is recommended as the primary design basis given its Anderson-Darling performance, but the full distributional range should inform the capacity review as an explicit uncertainty envelope. Future research can evaluate sensitivity to future land use and climate change, extend the rainfall record, and employ a peaks-over-threshold series to incorporate the Generalised Pareto Distribution.

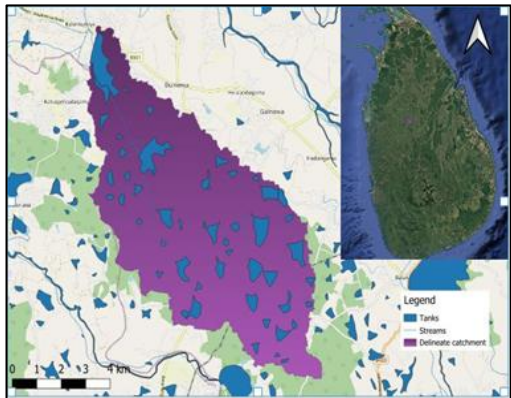
References

- [1] H. Zhang, L. Chen, and V. P. Singh, "Flood frequency analysis using generalized distributions and entropy-based model selection method," *J. Hydrol.*, 2020, Art. no. 125610, doi: 10.1016/j.jhydrol.2020.125610.
- [2] R. S. Khwairakpam and S. Kundu, "Significance of different probability distributions in flood frequency analysis of Brahmani-Baitarani River Basin, India," *Discov. Geosci.*, vol. 2, no. 1, pp. 1–20, 2024.
- [3] J. F. England, T. A. Cohn, B. A. Faber, J. R. Stedinger, W. O. Thomas, A. G. Veilleux, J. E. Kiang, and R. R. Mason, *Guidelines for Determining Flood Flow Frequency—Bulletin 17C*. Reston, VA: U.S. Geological Survey Techniques and Methods, book 4, chap. B5, 2018.

Distributional Uncertainty in Design Rainfall Reveals a Critical Spillway Capacity Deficit at Kalankuttiya Reservoir, Mahaweli System H, Sri Lanka

53 km ²	31 year	6	45–59 m
Catchment area	Rainfall record used	Distributions compared	Required spillway (vs 18 m existing)

STUDY AREA

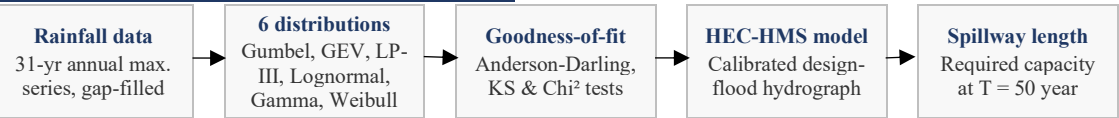


Delineated catchment (53 km²) with tank network, Kalankuttiya, Mahaweli System H

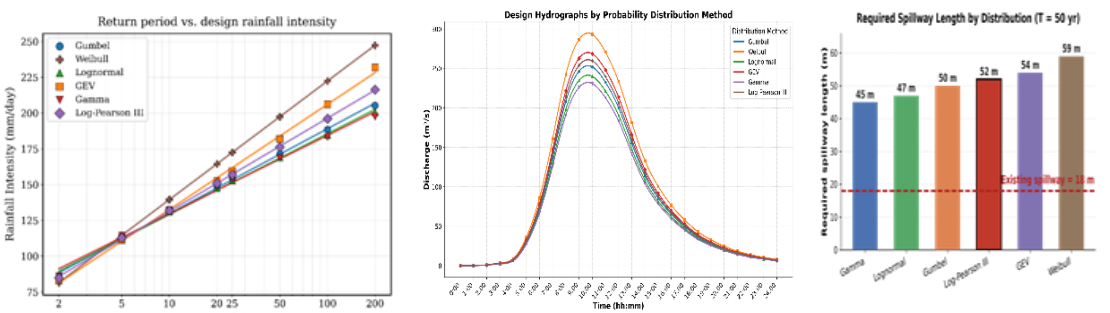


Catchment area: 53 km²
Existing spillway: 18 m long
Rainfall record: 31-yr annual maximum daily rainfall, Siyambalangamuwa rainfall station

METHOD



RESULTS



Design rainfall vs. return period, by distribution Design hydrographs ($T = 50$ years), by distribution Required spillway length vs. existing 18 m spillway

- $T = 50$ -year flood: $Q = 230.8\text{--}293.1 \text{ m}^3/\text{s}$
- Required spillway length: 45–59 m
- Existing spillway: 18 m
- Capacity gap: 27–41 m
- Design basis: Log-Pearson III