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FLOOD TYPING AND MIXED POPULATION STUDY

By
Chandramauli Awasthi[1] and Stacey A. Archfield[2]

1. Department of Civil, Construction, and Environmental Engineering
   North Carolina State University
   Raleigh, NC

2. U.S. Geological Survey
   Water Resources Mission Area
   Reston, VA

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Chandramauli Awasthi[1], Stacey A. Archfield[2],

[1] Department of Civil, Construction, and Environmental Engineering, North Carolina State University, NC, USA, fchandr@ncsu.edu

[2] U.S. Geological Survey, Water Resources Mission Area, Reston, VA, USA, sarch@usgs.gov

Principal Investigator

Dr. Sankarasubramanian Arumugam

Department of Civil, Construction, and Environmental Engineering, North Carolina State University, NC, USA,

E-mail: sankar_arumugam@ncsu.edu

Phone: 919-515-7700

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Abstract

Flood frequency analysis is critical for managing flood risk, designing hydraulic structures, and developing floodplain management strategies. Accurately estimating the flood peak of varying associated risks can significantly reduce potential hazards to water infrastructure and human life. Despite long-standing recognition of the diverse nature of floods caused by different hydrological and meteorological processes, traditional flood frequency analysis methods often assume a homogeneous population of flood events. This study investigates five flood frequency approaches suitable for mixed flood distribution populations and evaluates their applicability to rivers experiencing floods from multiple hydrological processes. We aim to address three key research questions: (a) when application of a mixed frequency model is needed, (b) how an expert-based flood classification compares with a purely data-driven flood classification technique, and (c) which mixed flood frequency model can best estimate flood quantiles for varying return periods. First, we systematically conduct synthetic experiments to explore the application of the considered models, followed by their application to selected natural basins in the USA. The implications of this study extend to various stakeholders, including engineers, planners, and policymakers. By adopting a mixed population flood frequency analysis, decision-makers can gain a deeper understanding of flood risk, leading to more informed and effective flood mitigation strategies. Future research directions include refining the classification of flood-generating mechanisms and exploring the application of mixed population models in different climatic and geographical contexts.

1. Introduction and Objectives

Floods are among the most devastating natural disasters causing significant damages to economy, environment, and human life. Flood frequency analysis, a fundamental aspect in hydrology and water resources engineering, is crucial for designing hydraulic structures, managing flood risk, and developing floodplain management strategies. Thus, an accurate estimation of flood risk and associated flood volume is essential for reducing potential threat to water infrastructure and human life. Traditional flood frequency analysis approaches assume that floods are caused by a homogeneous population governed by a single flood distribution (England et al., 2018). Though this assumption simplifies the flood modelling and estimation, but it may lead to inaccuracies in flood risk estimation for basins experiencing floods caused by more than one physical processes. Singh and Sinclair (1972) and Singh (1987) were among the first ones questioning the appropriateness of homogeneous distribution for fitting flood data for basins witnessing mixed populations. Later Alila and Mtiraoui (2002) found that mixed population method fitted the flood data better than the conventional direct fitting method and hence resulting into more reliable flood estimates. Such previous studies have highlighted the need to explore and improve our understanding of different flood generating processes and to develop methods for flood frequency analysis in the context of mixed population. To this end, this WRRI project carried out the following objectives:

1. Review the existing literature on mixed flood frequency analysis approaches
2. Select some approaches based on the literature review and identifying their advantages and disadvantages
3. Design a set of synthetic experiments informed by manual typing findings to conduct a multi-model comparison of the selected approaches
4. Apply and investigate the utility of different approaches on selected pilot regions
5. Develop a framework including a data-driven Bayesian based flood typing followed by application of selected mixed distribution approaches.

Results and interpretation are subject to USGS scientific integrity policies, which require internal peer review and formal approval. Therefore, this report addresses the minimum requirements of the USGS coordination grant reporting requirements to "include a comparison of actual accomplishments with the established goals and objectives of the award; a description of reasons why established goals were not met, if appropriate; and any other pertinent information relevant to the project results."

2. Comparison of objectives with accomplishments

The established objectives above were fully completed on time and the quality of work of the Water Resources Research Institute (WRRI)-funded project member exceeded expectations. Based on a review of the existing literature regarding methods to apply mixed-population flood-

frequency analysis, the WRRI-funded researcher identified 4 promising modeling approaches: (1) local polynomial regression, (2) the mixture distribution model, (3) the mixture moments model, and (4) the Monte Carlo model. A fifth approach - the single population model - which was used as the baseline model representing the flood-frequency approach currently used in practice and that assumes no mixed population is present in the flood series.

The researcher then devised a set of novel, controlled hypothesis test of known but complex truths to evaluate and compare these candidate approaches with the baseline model that assumes no mixed population is present in the data. Controlled experiments are necessary because no data-based validation methods exist in practice to test how close each method approximates the true, known estimates of mixed-population flood frequencies. These experiments explored cases where two populations in the flood series each have distributions with: (a) similar values in the mean and low values of variance, (b) dissimilar values in the mean and high values of variance, (c) dissimilar values in the mean and low values of variance, and (d) similar values in the mean and high values of variance.

The ability of each method to estimate the known truth – that is the flood frequencies – were compared. Based on the results from all four modeling approaches, the researcher observed that when two distributions have low difference in mean value or high variance (case (a) above), the conventional single population model performs relatively better than the other models. For other behaviors between two distributions (cases (b)-(d) above), the mixture distribution model performs better than any of the other models.

Test cases of real-world applications of these approaches were applied to 7 pilot watersheds in diverse hydroclimatic areas across the U.S. to understand how mixed population approaches can be applied in practice and the advantages and disadvantges of each approach.

Research results were communicated in a report to the USGS, USACE, and FEMA for incorporation into a larger report that is being prepared for completion in 2026.

3. References

Alila, Y., Mtiraoui, A., 2002. Implication of heterogeneous flood frequency distributions on traditional stream-discharge predic tion techniques. Hydrological Processes 16, 1065–1084.

England Jr, J. F., Cohn, T. A., Faber, B. A., Stedinger, J. R., Thomas Jr, W. O., Veilleux, A. G., ... & Mason Jr, R. R. (2018). Guidelines for determining flood flow frequency—Bulletin 17C (No. 4-B5). US Geological Survey.

Singh KP, Sinclair RA. 1972. Two-distribution method for flood-frequency analysis. Journal of Hydraulics Engineering, American Society of Civil Engineers 98(HY1): 29–44.

Singh KP. 1968. Hydrologic distributions resulting from mixed populations and their computer simulation. International Association of Scientific Hydrology Publication 81: 671–191.

Appendix 1

FEMA	Federal Emergency Management Agency
USACE	US Army Corps of Engineers
USGS	US Geological Survey
WRRI	Water Resources Research Institute

Appendix 2

Presentations

Chandramauli Awasthi and Stacey A. Archfield, 2024, A Comprehensive Mixed Flood Frequency Analysis: Where, When, and How? *American Geophysical Union Annual Meeting*, Washington DC, December 2024.

Chandramauli Awasthi, Stacey A. Archfield, Brian J. Reich and Sankarasubramanian Arumugam, 2024, Can Trend Tests Detect Changes in Design-Flood Quantiles under Changing Climate? *European Geosciences Union General Assembly*, Vienna, Austria, April 2024.

Chandramauli Awasthi, Stacey A. Archfield, Brian J. Reich and Sankarasubramanian Arumugam, 2023, Beyond Simple Trend Tests: Detecting Significant Changes in Design-Flood Quantiles, *13th International Workshop on Statistical Hydrology*, Boston, MA, September 2023.

Communication of results to stakeholders

Regular monthly meetings with the US Army Corps of Engineers (USACE) (bi-weekly) and the Federal Emergency Management Agency (FEMA) to update them on progress and interim results.

Provided a preliminary report titled, “TASK 4C: Mixed Distribution Modelling Approaches” to USACE, US Geological Survey (USGS), and FEMA for completion of stated objectives. This report is a draft and subject to USGS approval before it can be released.