1.Civil and Environmental Engineering, University of Virginia
2.Civil and Environmental Engineering, University of Wisconsin-Madison

Evaluating the design relevance of the choice of flood frequency analysis technique in an urban coastal watershed

Daniel Lassiter[1] LinkedIn
Julianne Quinn[1] Quinn Lab Group Website
Daniel Wright[2] Wright Lab Group Website

1 Motivation

- Consistent standards for quantifying the probability of design-relevant flood statistics in coastal areas subject to compound floods are lacking
- Flood management practices are often designed to handle flood volumes, the quantity of water that exceeds the capacity of existing infrastructure
- This study compares two techniques for assigning probabilities to flood volumes, a novel Stochastic Approach and a more typical Design Storm Approach

2 Methods

Data

- Precipitation: Radar derived precipitation data on a 1x1km grid over CONUS from 2001-2011, 2015-2022 consolidated to an hourly timestep (originally between 2 and 5 minutes)[1]
- Water levels: Tide gage data at a 6-minute recording interval from 2001-2022
- SWMM Model: 1.9km^2 with 1,133 nodes, 1,144 links, and 869 subcatchments overlapping 5 radar grid cells

Stochastic Approach:

1. Perform event selection on observed rainfall and storm surge data (n=483)
2. Fit a multivariate Gaussian copula to event total rain depth, average rainfall intensity, maximum rainfall intensity, peak storm surge, and the lag time between peak rainfall intensity and peak storm surge
3. Perform K-means clustering on observed events with same variables (K = 5)
4. Use Stochastic Storm Transposition[2] to generate 20 rain event time series per year for 1,000 years
5. Simulate peak storm surge and lag times from the copula conditioned on SST-derived rainfall
6. Stochastically select and rescale observed water level time series by classifying the simulated event using the K-means model, randomly selecting an observed event from the same category, rescaling the observed event to match the simulated peak, and shifting the observed event in time to match the simulated lag
7. Run all events through an urban coastal SWMM model
8. Compute flood volume return periods empirically and using the Pearson type III probability distribution function

Design Storm Approach:

1. Create rainfall time series for each event by determining 24-hour rain depths associated with desired return periods and distributing those depths over unit rainfall time series
2. Assume constant downstream water level for event duration either with a return period equal to the rainfall return period (complete dependence) or equal to a typical water level (complete independence)
3. Run design storms through SWMM model
4. Assume flood volume return periods are equal to the rainfall return periods

3 Results

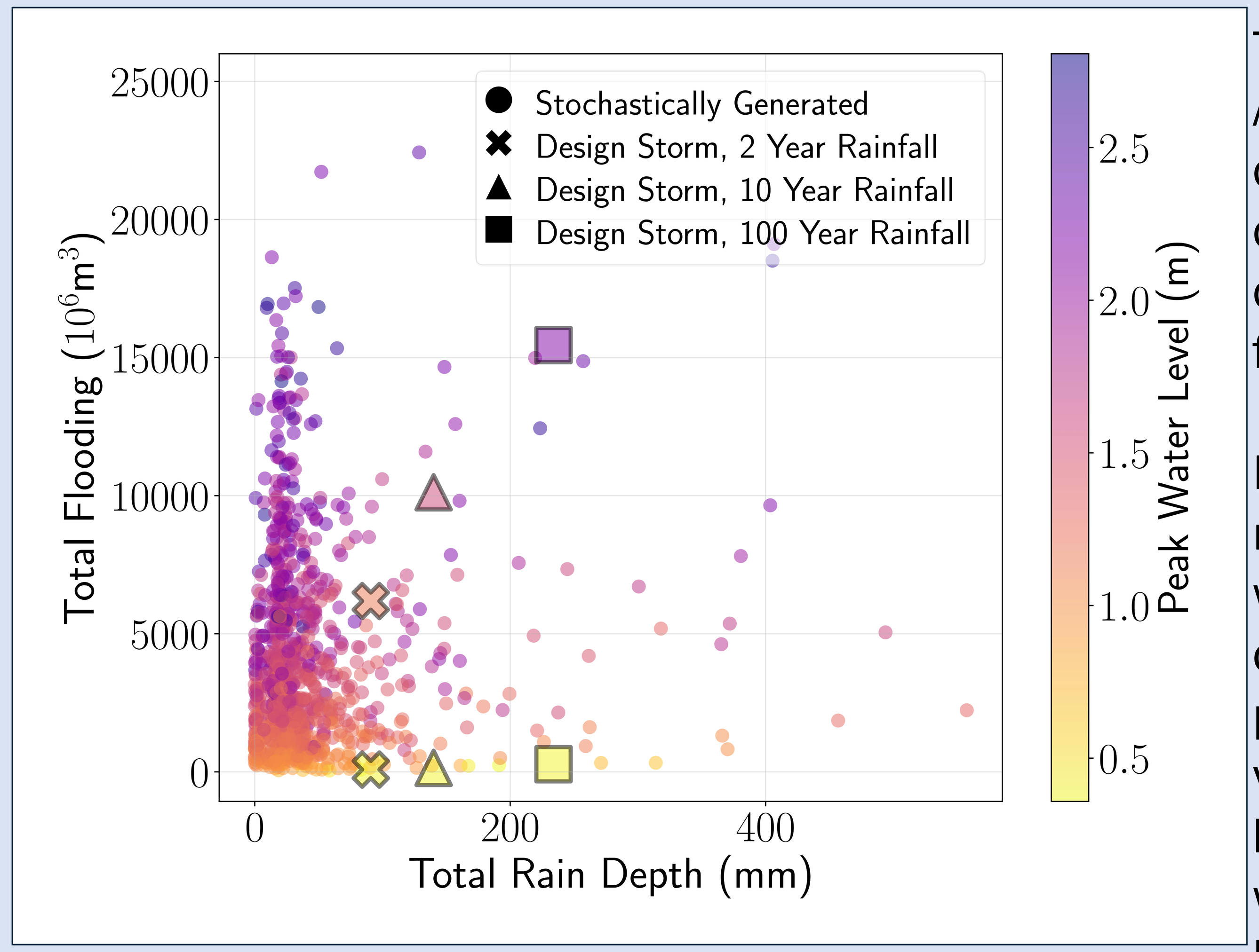

Figure 1: Total flooding vs. rain depth and peak water level for each simulated event

The Stochastic Approach has more coverage of conditions that contribute to flooding

Flood volumes are more sensitive to water level than rain depth, but the primary driver will vary between location and event which cannot be known *a priori*

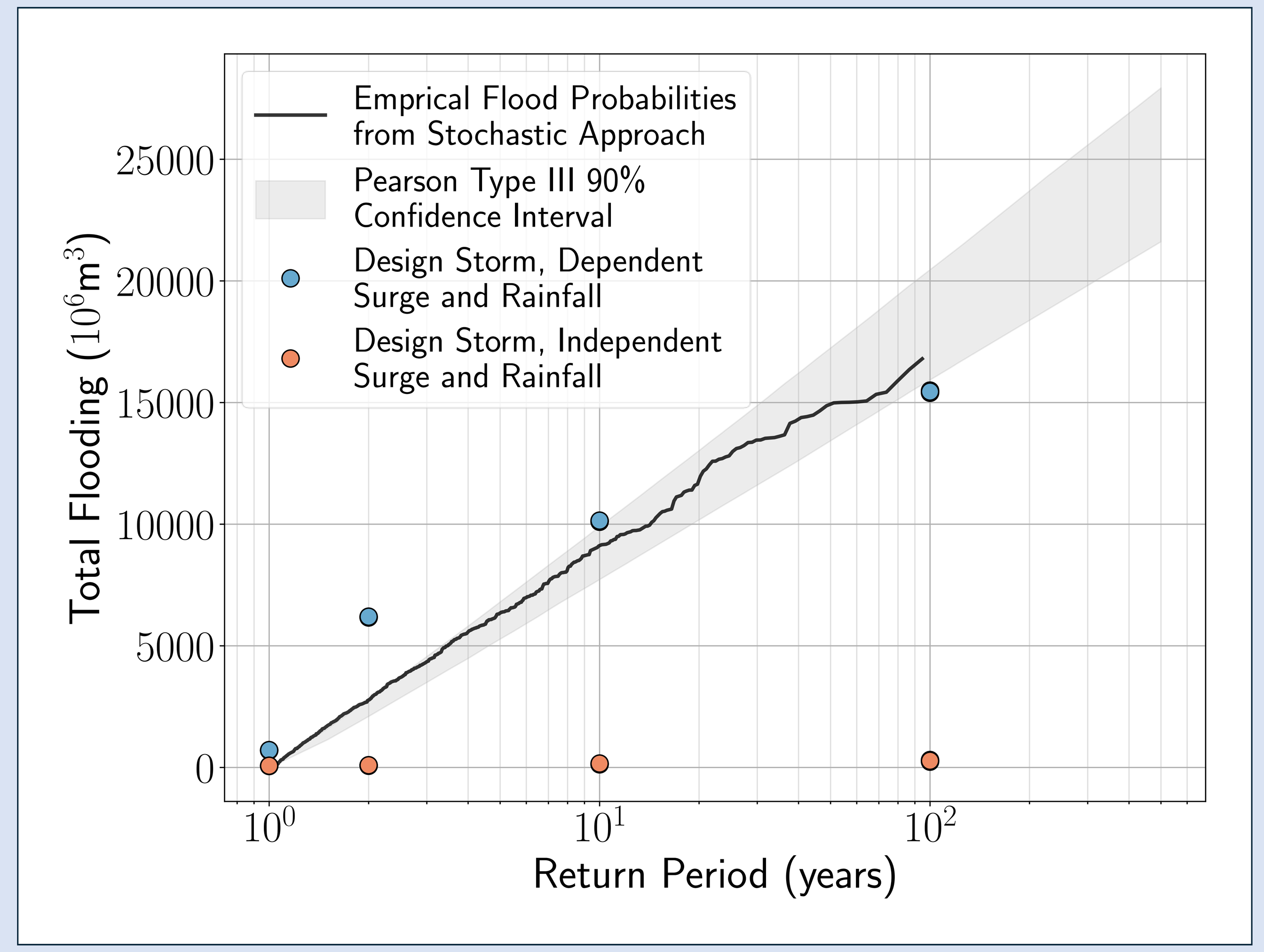

Figure 2: Flood volume exceedance curve comparing the results of the Stochastic Approach and Design Storm Approach

The Stochastic Approach results in less uncertainty in flood volumes at each return period

Assuming dependence of rainfall and storm surge in the Design Storm Approach yields under- and overestimated flood volumes

4 Conclusions

▶ Using a typical Design Storm Approach risks under- and over-design for coastal flood mitigation

▶ The Stochastic Approach incorporates considerations that may influence the evaluation of flood mitigation alternatives

Considerations:	Stochastic Approach	Design Storm Approach
Statistical relationships of rainfall and storm surge	✓	✗
Spatiotemporal variability in rainfall and storm surge	✓	✗
Spatiotemporal variability in dominant flood driver	✓	✗

5 References

[1] 1. Zhang, J. et al. Multi-Radar Multi-Sensor (MRMS) Quantitative Precipitation Estimation: Initial Operating Capabilities. Bulletin of the American Meteorological Society 97, 621–638 (2016).
[2] 1. Wright, D. B., Mantilla, R. & Peters-Lidard, C. D. A remote sensing-based tool for assessing rainfall-driven hazards. Environmental Modelling & Software 90, 34–54 (2017).

All code needed to reproduce this analysis can be found in my GitHub repository https://github.com/lassiterdc/stormy.

The repository https://github.com/lassiterdc/highres-radar-rainfall-processing explains the processing steps taken to use the radar-derived precipitation data with Daniel Wright's stochastic storm transposition software, RainyDay, which can be found here: https://github.com/danielbwright/RainyDay. If you would like access to rainfall data, feel free to reach out to me over LinkedIn or via email (dcl3nd@virginia.edu) and I can provide you with a link to a public Globus endpoint. The dataset is roughly 3.5TB in total.