Evaluating Uncertainty in FEMA Flood Insurance Rate Maps (FIRMs) using Bayesian Model Averaging (BMA) and Hierarchical BMA

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November 24, 2022

Abstract

Flood Insurance Rate Maps (FIRMs) managed by the Federal Emergency Management Agency (FEMA) have been providing ongoing flood information to most of the communities in the United States over the past half century. However, the uncertainty associated with the modeling of the FIRMs, some of which are created by using a single HEC-RAS one-dimensional (1D) steady flow model, may have adverse effects on the reliability of flood stage and inundation extent. Therefore, a systematic understating of the uncertainty in the modeling process of FIRMs is important and necessary. The Bayesian model averaging (BMA), which is a statistical approach that can combine estimations from multiple models and produce reliable probabilistic predictions, is applied to evaluating the uncertainty associated with the FIRMs. In this study, both the BMA and HBMA approaches are used to quantify the uncertainty within the detailed FEMA models of the Deep River and the Saint Marys River in the state of Indiana based on water stage predictions from 150 HEC-RAS 1D unsteady flow model configurations that incorporate four uncertainty sources including the bridges, channel roughness, floodplain roughness, and upstream flow input. The BMA weight and the variance for each model member are obtained given the ensemble predictions and the observed water stage data in the training period, and then the BMA prediction ability is validated for the observed data from the later period. The results indicate that BMA prediction is more robust than the original FEMA model as well as the ensemble mean. Different types of uncertainty coefficients based on the BMA prediction distribution are also proposed to evaluate the FEMA models. Furthermore, the HBMA framework shows that both the channel roughness and the upstream flow input have a larger impact on prediction variance than bridges, and hence provides some insights for modelers into the relative impact of individual uncertainty sources in the flood modeling process.

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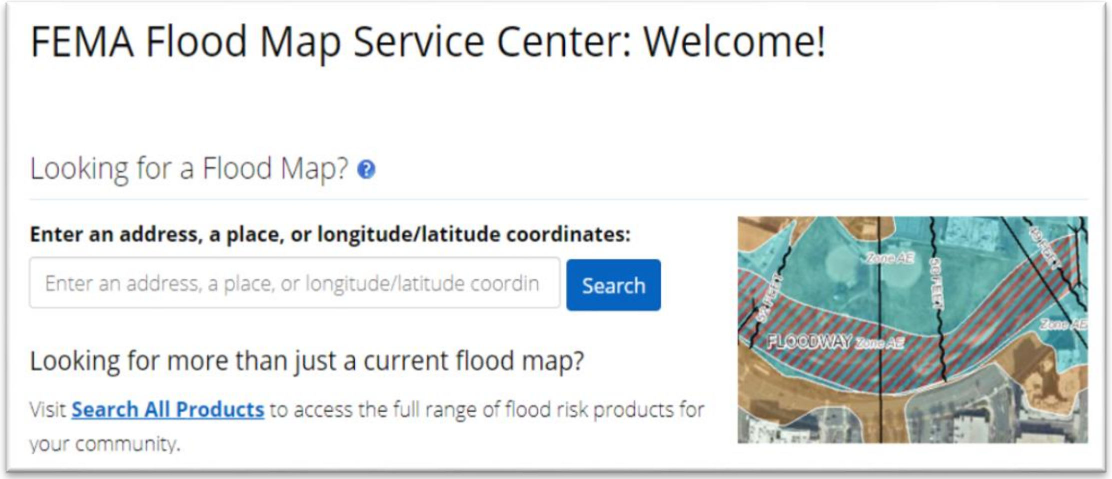
December 2021

AGU FALL MEETING

Are FIRMs really firm?

- Flood insurance rate maps (FIRMs) from a single hydraulic model (HEC-RAS 1D steady flow analysis) include uncertainty from different sources

➢ **Objectives**
- assess the uncertainty in FIRMs
- demonstrate the uncertainty propagation
- prioritize the relative impact of individual uncertainty sources
- compare 100-year BMA probabilistic flood maps with FIRMs



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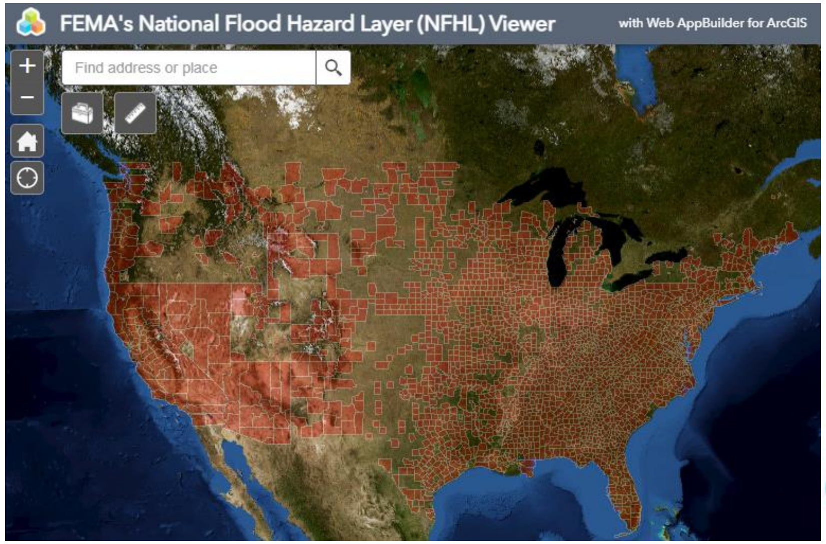

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Image source:
[1] https://msc.fema.gov/portal/home
[2] https://msc.fema.gov/nfhl

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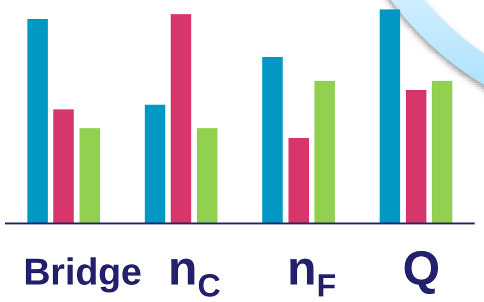
Methodology

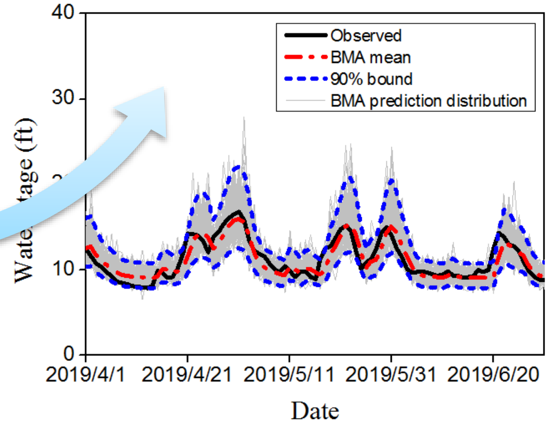
Models of FIRMs

- Model structure (steady & bridge)
- Model parameter (roughness)
- Model input (streamflow data)



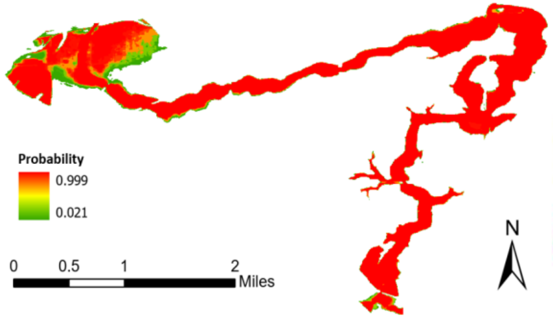
BMA Analysis

- HEC-RAS model configurations
- Observed hydrologic data
- BMA weight & variance



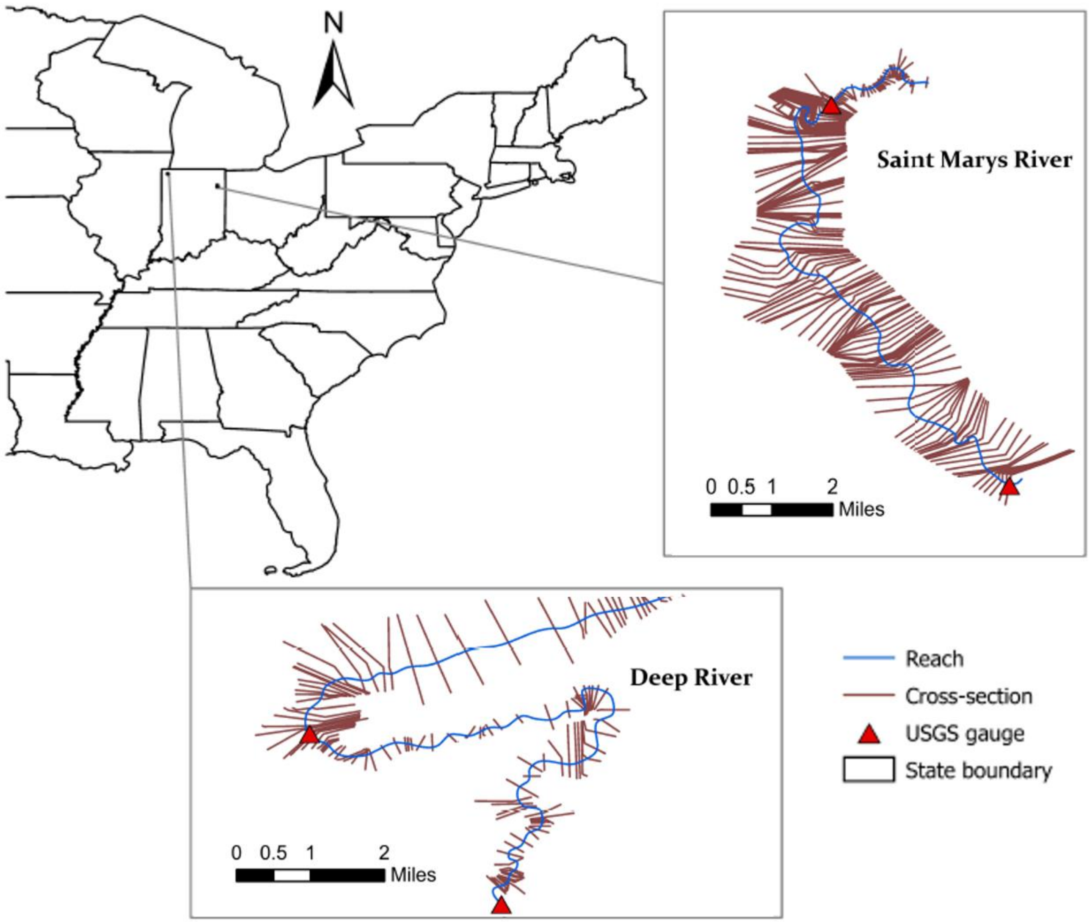
Probabilistic Flood Maps

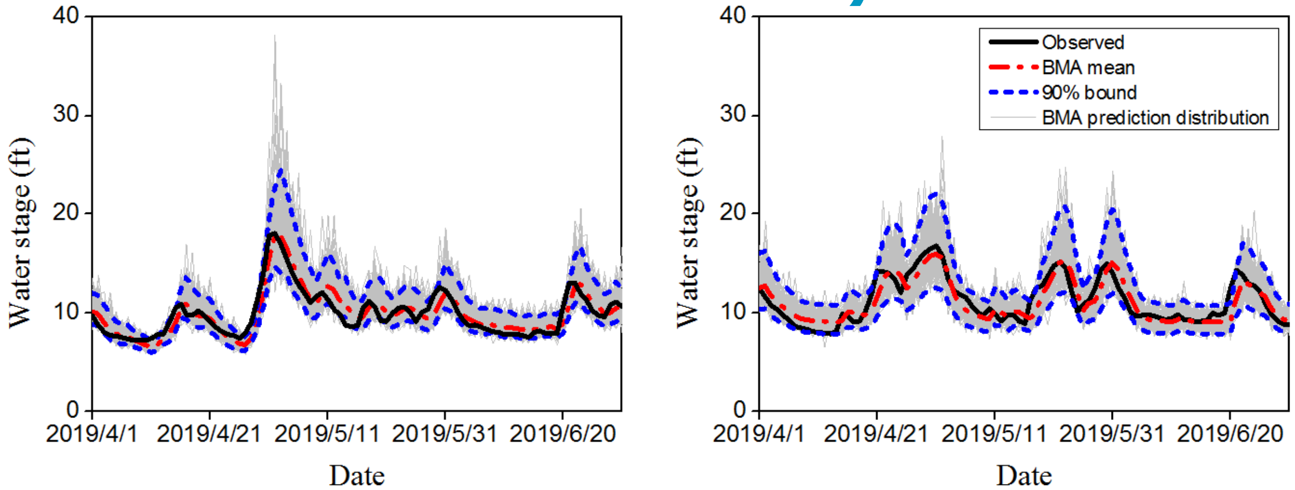
- Prediction distribution of water stage
- Propagation of uncertainty
- Probability of inundation extents



SCIENCE is SOCIETY

Case Study of Two Rivers in Indiana, USA

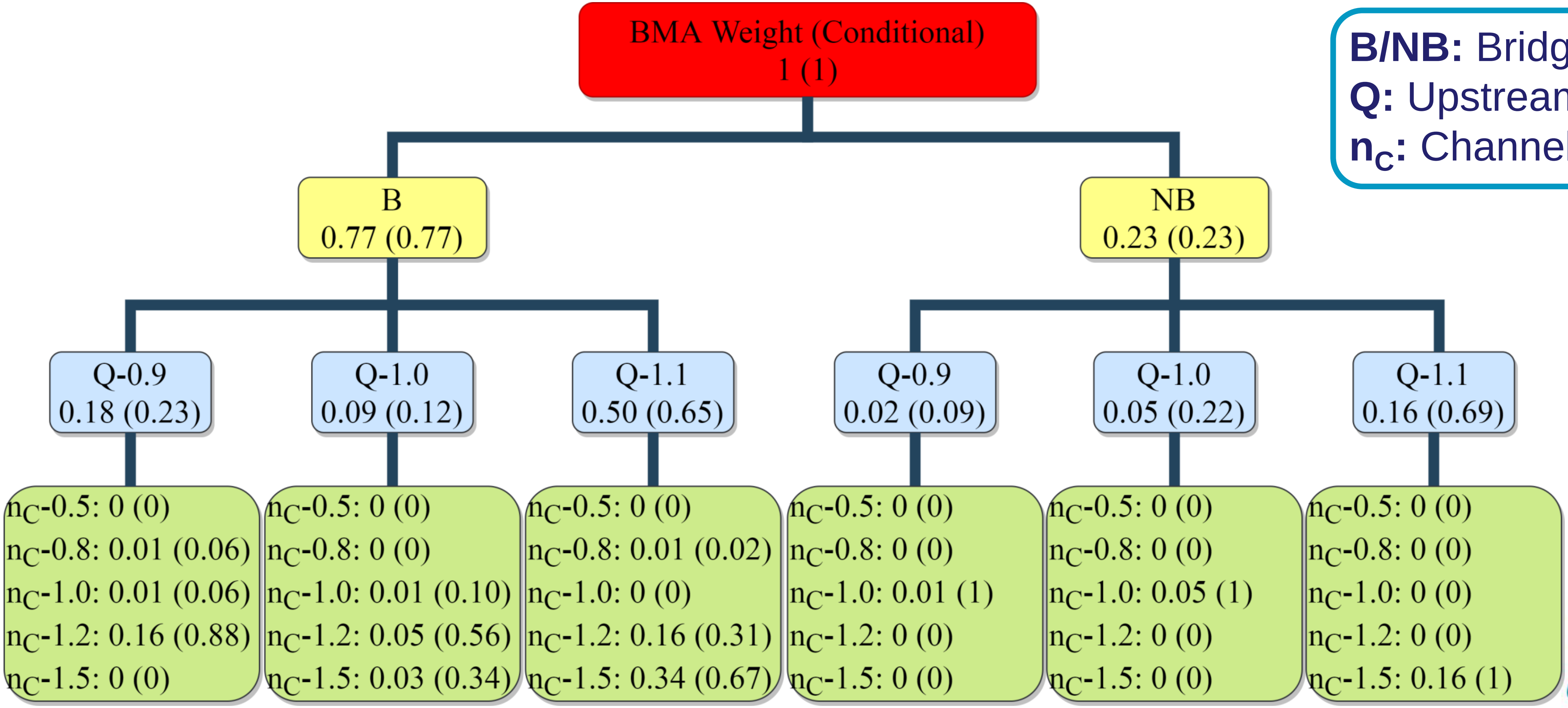




Type	Uncertainty Coefficient	Deep River	Saint Marys River
UC1	90%-Prediction interval (Average interval width)	13.19% (3.35 ft)	4.40% (4.63 ft)
UC2	1-*NSE*	17.24%	21.61%
UC3	1-R^2	17.05%	21.54%

Uncertainty Propagation in HBMA Framework

B/NB: Bridges/None
Q: Upstream flow input
n_C: Channel roughness



HBMA framework of model weights and conditional weights for Deep River

THANK YOU

"An answer that used to be a single number may now be a statistical distribution."

– Nick Trefethen

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