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Precipitation Frequency Applied Research and Development for the United States Army Corps of Engineers Dam and Levee Safety Program

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INTRODUCTION & AIM

Extreme precipitation frequency areal estimates over watersheds are a key component in estimating flood hazards and hydrologic risk. Current practice in precipitation frequency for dam safety within the US Army Corps of Engineers (USACE) uses GEV/L-moments and areal reduction factors.

Advances from the field of extreme value theory (EVT) have demonstrated the capacity to efficiently, flexibly, and credibly model spatial extremes of pointwise maxima using a max-stable process (MSP), the infinite-dimensional analog of the multivariate extreme value distribution.

MSP models explicitly account for the spatial dependence of the extreme data. They do not depend upon the subjective assumptions associated with a Regional Precipitation Frequency Analysis, for example, the definition of homogeneous subareas and the need to convert point estimates into areal average depths using uncertain empirical regional depth-area reduction factors. They also do not share a disadvantage of an RFA which does not construct an explicit spatial model for the marginal parameters. With their application, one can not only compute pointwise return level maps, but also model the joint distribution and more complex areal-based assessments of risk while working within the theoretically justified mathematical framework provided by EVT [1].

METHOD

MSP model fitting can be thought of as a two-step procedure involving trend surface and simple MSP model selection, with each step assuming independence among the extremes and fixed unit Fréchet margins, respectively. The composite (pairwise) likelihood-based approach often used to fit a simple MSP model can be readily adapted to accommodate the simultaneous estimation of trend surface and dependence parameters.

Trend surfaces are functions of geographical and/or climatological covariates that influence regional precipitation extremes to model the spatial variation of the location, $\mu(x)$, scale, $\sigma(x)$, and shape, $\xi(x)$, parameters of the known generalized extreme value (GEV) marginal distributions. For example, linear trend surfaces are of the form

$$\mu(x) = \eta_{\mu,0} + \eta_{\mu,1} cov_{\mu,1} + \cdots + \eta_{\mu,n_\mu} cov_{\mu,n_\mu}$$
$$\sigma(x) = \eta_{\sigma,0} + \eta_{\sigma,1} cov_{\sigma,1} + \cdots + \eta_{\sigma,n_{\mu\sigma}} cov_{\sigma,n_\sigma}$$
$$\xi(x) = \eta_{\xi,0} + \eta_{\xi,1} cov_{\xi,1} + \cdots + \eta_{\xi,n_\xi} cov_{\xi,n_\xi}$$

where $\eta_{\cdot,i}$ and $cov_{\cdot,i}$ are the parameters and covariates of the linear trend surface for $\mu(x)$, $\sigma(x)$, and $\xi(x)$, respectively. Linear trend surfaces for the marginal parameters were estimated by applying the methods described by Love et al. [2], which leveraged theory from spatial extremes and recent advances for regularizing general linear models.

With an MSP model, areal exceedance estimates are obtained by simulating multiple independent copies of the fitted process over an area of interest, using its fitted parameter estimates or random samples either gleaned from model calibration or application of the bootstrap method.

RESULTS & DISCUSSION

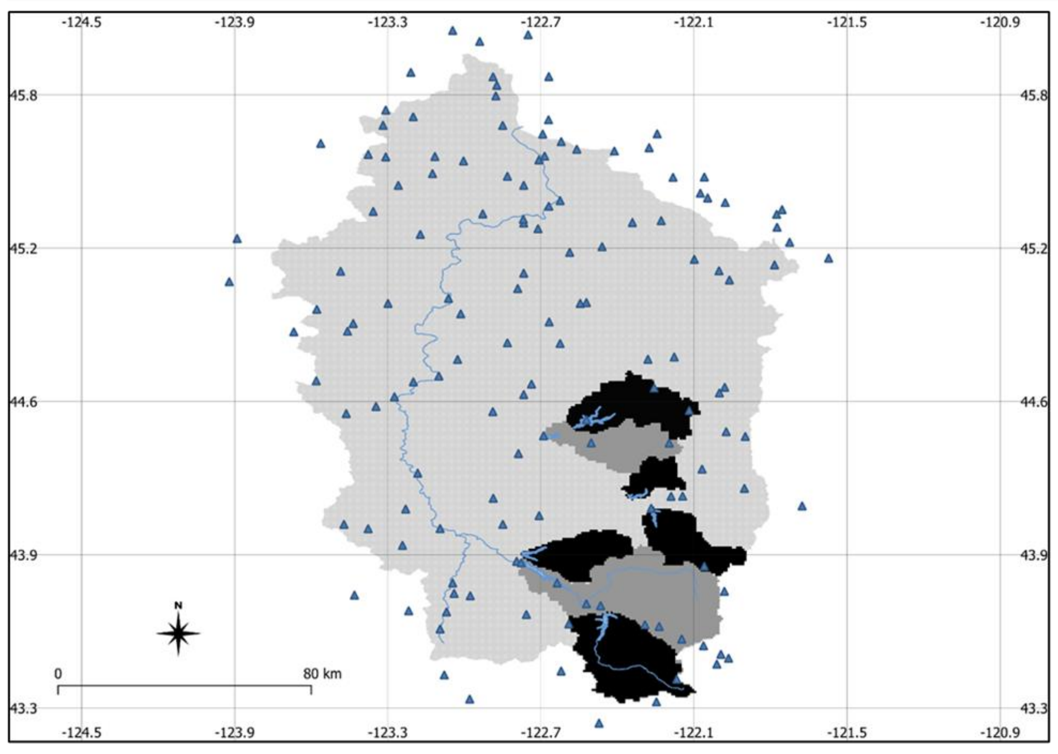

Figure 1. Map of the Willamette River Basin (WRB) in the State of Oregon, main stem of the Willamette River, seven dam safety projects (Hills Creek, Lookout Point, Fall Creek, Cougar, Blue River, Green Peter, Foster) for which areal exceedances were computed, footprints for their associated contributing drainage areas, and the 140 precipitation gages whose data were used for modeling analysis. The contributing drainage areas for Lookout Point and Foster included those for Hills Creek and Green Peter, respectively [3].

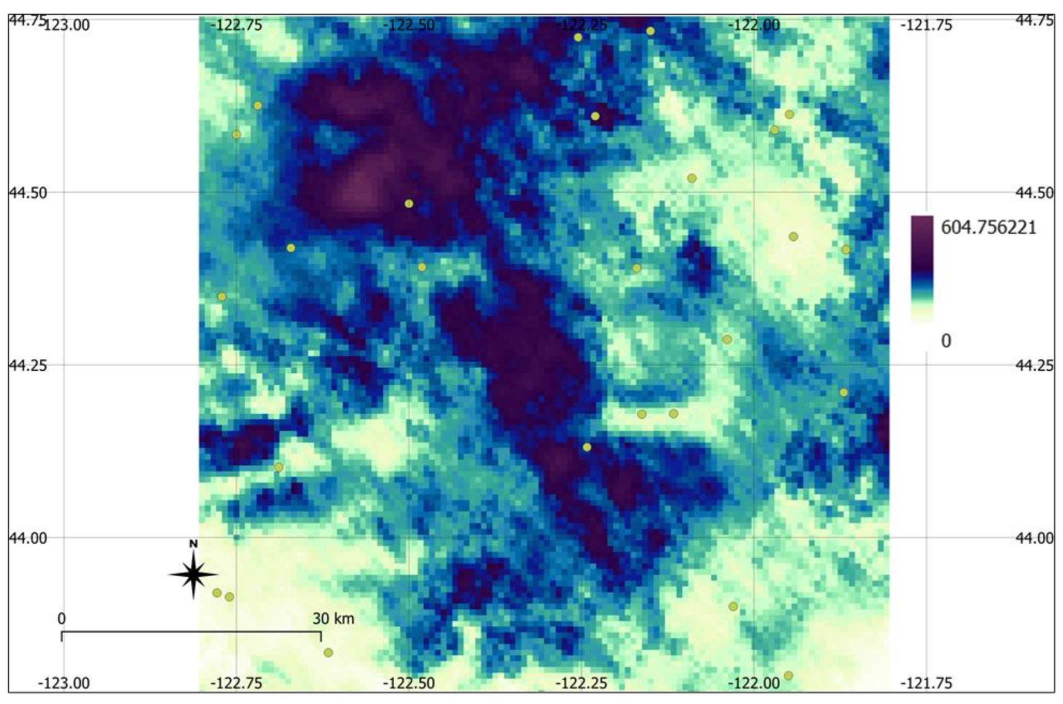

Figure 2. A cool season (October to April) three-day duration storm simulated for a 1° by 1° box located within the WRB. The storm was simulated using an extremal-t max-stable process with Whittle-Matern correlation function and the fitted model parameter estimates. Twenty-six of the 140 original precipitation gage sites (Figure 1) exist within the box region and are also shown. Simulated precipitation values are in mm [3].

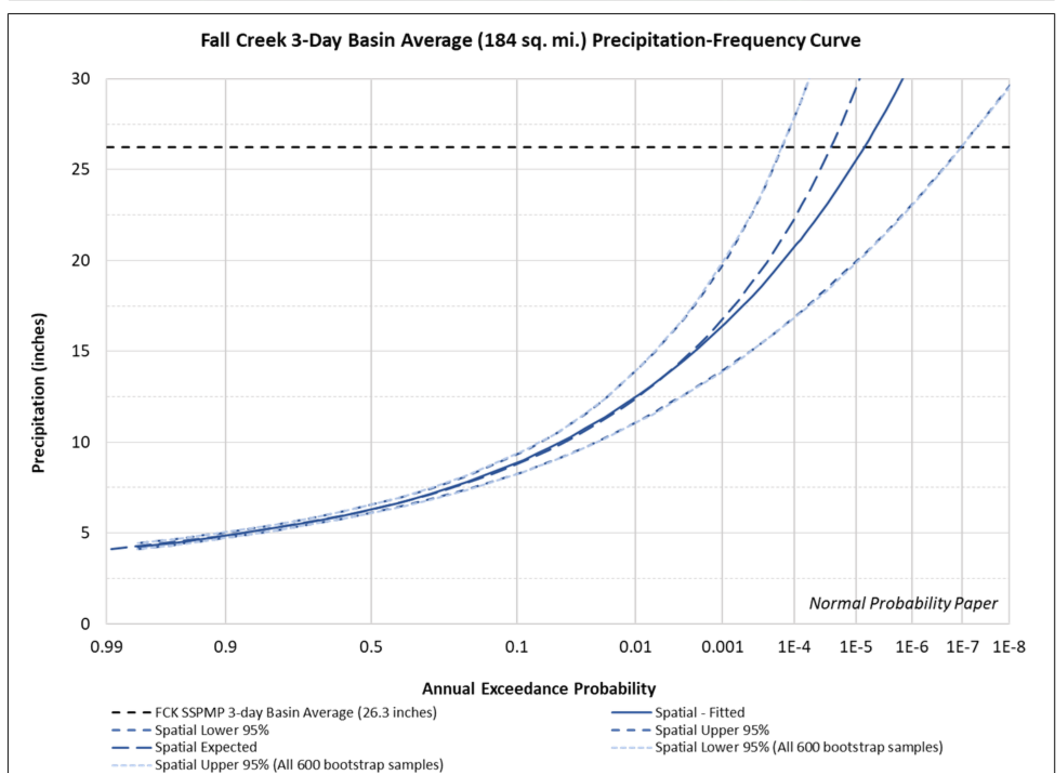

Figure 3. For the Fall Creek dam safety project study area in the Willamette River Basin, areal exceedance estimates, including uncertainty, calculated by simulating multiple independent copies of the MSP using its fitted values and random samples gleaned from application of the bootstrap method [3].

CONCLUSION

The application of an MSP model enables the estimation of areal-based exceedances within an EVT framework. It is inherently a spatial model, does not require a decomposition of a study area into homogeneous regions or the introduction of uncertain empirical areal reduction factors for computing areal exceedances, and it has a strong and coherent mathematical basis for model fitting, selection, extrapolation, and uncertainty quantification.

REFERENCES

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3. Skahill, B. Cool Season Extreme Precipitation Estimates for Seven Dam Safety Projects in Oregon's Willamette River Basin. *US Army Corps of Engineers Institute for Water Resources Risk Management Center Technical Report RMC-TR-2023-01* **2023**. http://dx.doi.org/10.13140/RG.2.2.16044.44166