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Uncertainty in Probable Maximum Precipitation for Dam Safety

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California's large network of dams is under increasing scrutiny as hydrologic extremes are becoming more frequent and dams are aging. Typically, dam spillways are sized for the most severe flood that is likely in a given watershed, called the Probable Maximum Flood (PMF). PMF is obtained from the Probable Maximum Precipitation (PMP), which is the greatest 72-hour depth of precipitation that is "meteorologically probable". Historically, PMP has been estimated by scaling depth-area-duration relationships obtained from severe historical storms. The scaling factor was estimated as the ratio of moisture available during that storm to the climatological maximum for the region. This PMP estimation approach, after which the spillways of most existing dams in California have been sized, has long been criticized as being somewhat arbitrary, although in practice it has led to relatively conservative spillway designs. Advances in both atmospheric models now facilitate a more rational basis for specifying PMP. Over the last decade, model-based PMP estimation frameworks have been developed whereby a severe historical storm is reconstructed and "maximized" using a regional atmospheric model. The most common approach to date, called relative humidity maximization (RHM) consists of setting relative humidity to 100% at the model boundaries, which has the effect of generating more precipitation ("maximum") than occurred in the actual storm. This addresses major limitations of earlier PMP techniques through (1) more realistic representation of storm physics, (2) applicability of the method to future climate, and (3) suitability for forcing hydrologic models for improved PMF estimation.

The work I present here addresses concerns regarding the sources of uncertainty in the RHM approach, such as choice of storm to reconstruct and maximize, and choice of model physics parametrizations that directly affect model-based PMP estimates. To do so I produce an ensemble of PMP estimates (rather than a single value) that samples the above-mentioned sources of uncertainty. I focus on three California study basins, all of which have large reservoirs and different topographic and hydroclimatic conditions: the Feather, Russian and Santa Ana River basins. Using the WRF model forced with ERA5 reanalysis, I first create an ensemble of 40 reconstructions based on 10 combinations of physics parametrizations for 4 severe historical storms (Dec. 1964, Feb. 1986, Jan. 1997, and Feb. 2019). Next, I modify the 40 reconstructions by maximizing the model boundary moisture fluxes. This results in an ensemble of 4 storm events, 10 physics combinations, and 2 PMP methods, yielding 80 PMP estimates from which to better assess uncertainty in PMP. Differences among the PMP estimates I obtain based on different storm events, model physics and PMP methods confirm the value of such an ensemble in providing a

measure of uncertainty in PMP estimates . Focusing on large dams in California, this work is intended to improve confidence in and utility of PMP estimates, which form the cornerstone of dam safety, and ultimately enable safer and more effective reservoir management as the climate continues to change.