UNCERTAINTY ANALYSIS USING MONTE CARLO TECHNIQUES IN THE HYDROLOGIC MODELING SYSTEM (HEC-HMS)

William Scharffenberg, HEC-HMS Lead Developer, U.S. Army Corps of Engineers Institute for Water Resources, Hydrologic Engineering Center, Davis, CA, William.A.Scharffenberg@usace.army.mil; Angela Duren, Hydraulic Engineer, U.S. Army Corps of Engineers, Portland District, Portland, OR 97204; Matthew Fleming, U.S. Army Corps of Engineers Institute for Water Resources, Hydrologic Engineering Center, Davis, CA, Matthew.J.Fleming@usace.army.mil

INTRODUCTION

Traditional hydrologic simulation has focused on developing algorithms to represent each of the components of the hydrologic cycle. A great deal of effort has been dedicated to developing physically appropriate process representations and parameter estimation techniques. The Hydrologic Modeling System (HEC-HMS) is one modeling framework that takes this approach with components for precipitation, snowmelt, transpiration, infiltration, runoff, and channel flow among others. An automatic parameter estimation tool is also available.

The modern hydrologic simulation approach is often limited by knowledge uncertainty and natural variability. Knowledge uncertainty describes both our inability to fully understand hydrologic processes and the situation where we lack the observational data necessary to parameterize models. Natural variability describes inherent unpredictability in boundary conditions such as climate or initial conditions like soil moisture. Due to the nonlinear nature of the mathematical models that represent natural systems, the uncertainties due strictly to boundary conditions, initial conditions, and model parameters are difficult to distinguish and therefore quantify. However, to the capture these uncertainties together, a Monte Carlo-based uncertainty analysis tool has been added to HEC-HMS to quantify both knowledge uncertainty and natural variability. It includes the ability to statistically sample model parameters using analytical distributions, with an option for the distribution to be a function of the month of the year. It also can link a dependent parameter to a previously sampled parameter through a relationship that includes an error term.

OVERVIEW OF NEW HEC-HMS CAPABILITIES

The hydrologic modeling software, HEC-HMS, is used for dam and levee safety studies, flood damage reduction studies, real-time operations, and general planning studies. The latest version of HEC-HMS now has an integrated uncertainty assessment capability to allow for the development of probabilistic results for key metrics such as total runoff volume or maximum reservoir pool elevation.

The HEC-HMS uncertainty analysis features the ability to assign probability distributions to hydrologic model parameters such as soil loss rates, unit hydrographs, baseflow, and channel routing. Current available analytical distributions that can be assigned to parameters include beta, exponential, gamma, log normal, normal, triangular, and Weibull. Random numbers are generated using the Well19937c generator (Panneton, L'Ecuyer, and Matsumoto, 2006). Output includes the sampled parameters, key metrics, and selected time-series. As an example, the key

metrics can be processed to obtain histograms (Figure 1) or estimate the 90 percent non-exceedance value.

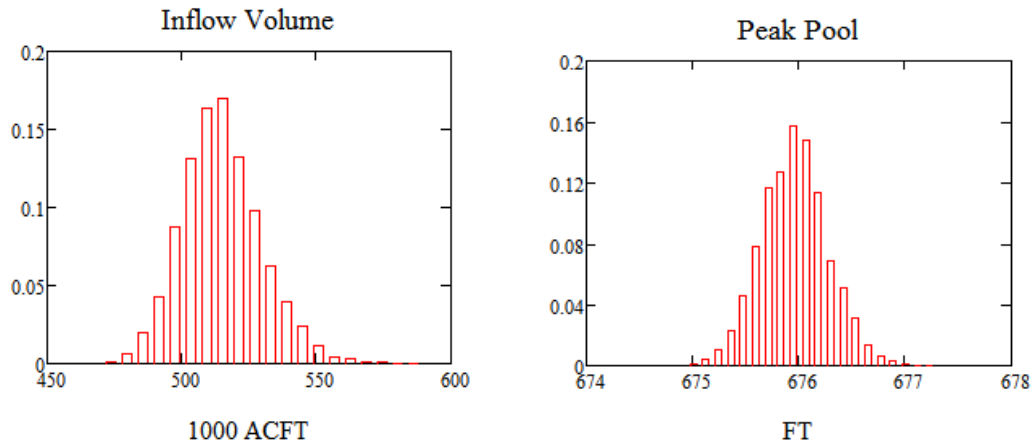

Figure 1 Example of Distribution of Inflow Volume or Peak Pool Results

IMPACT OF STOCHASTIC ANALYSIS ON POOL STAGE FREQUENCY

A study was conducted to compare a deterministic estimate of a reservoir pool stage frequency curve to an estimate generated from the new uncertainty assessment feature in HEC-HMS. The deterministic case assumed fixed parameters for loss rates while the uncertainty assessment used probability distributions estimated from calibration data. The minimum, mean, and maximum pool stage frequency curves from the uncertainty analysis are shown in Figure 2, along with the deterministic estimate. This case shows the deterministic estimate above the mean, notably so in the lower probability range which is an area of interest when performing a risk assessment for dams. Although the deterministic estimate is within the confidence limits computed from the minimum and maximum of the uncertainty analysis, the difference between the deterministic and mean stochastic estimates was profound in this study. The loss rates used in the deterministic model lie in the 'less probable' (and low soil loss) region of the estimate for the soil loss uncertainty distribution. By incorporating the estimated distribution of loss rates into the final pool stage frequency curve, a wider range of soil loss is sampled, thereby reducing the amount of runoff and peak pool stage.

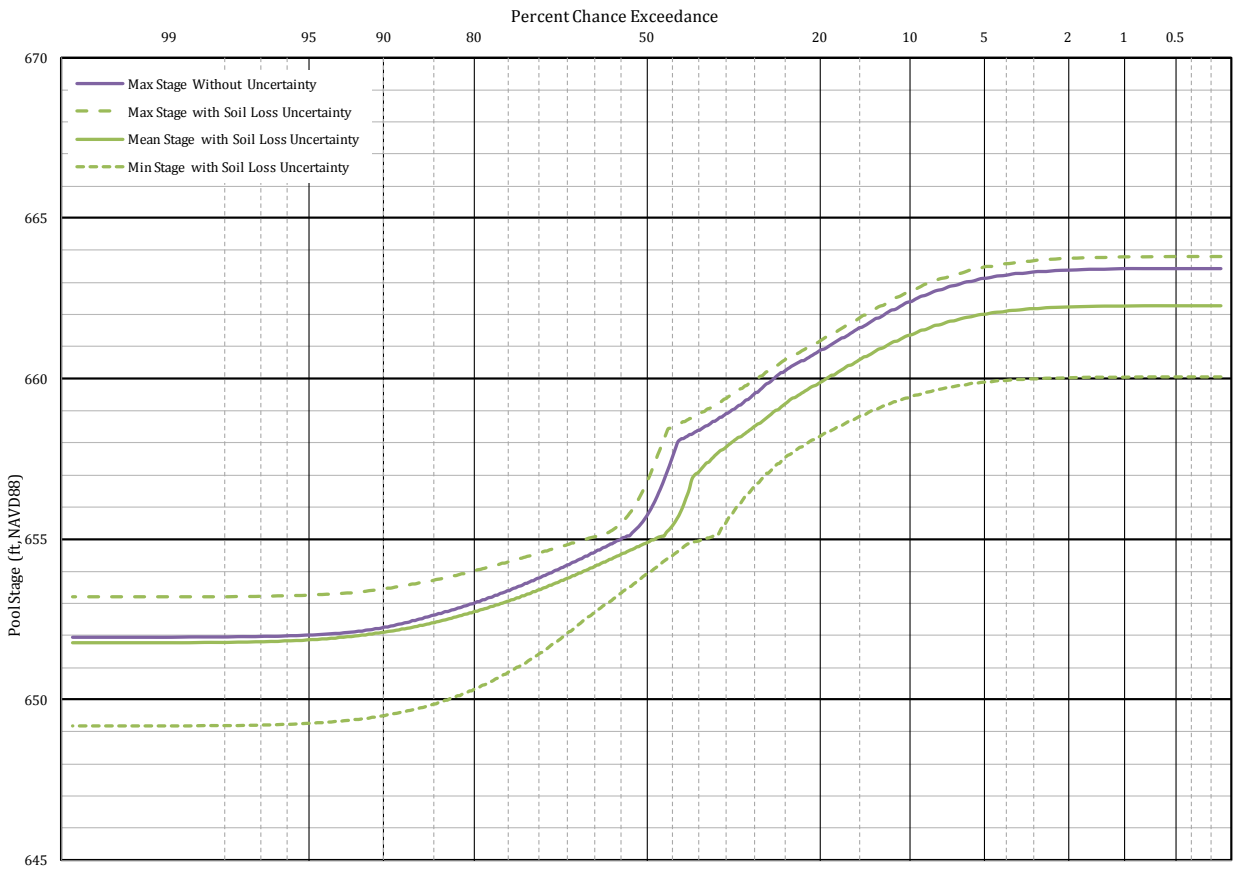

Figure 2 Pool Stage Frequency Example

EVOLUTION OF PROBABILITY DISTRIBUTIONS FOR HYDROLOGIC MODELING PARAMETERS

The most critical requirement for capturing knowledge uncertainty and natural variability in pool stage frequency curves or inflow volume is having the tools to account for the uncertainties in the parameters and having the probability distributions of the parameters themselves. Little work has been done to capture the probability distributions in hydrologic modeling parameters such as soil loss rates or unit hydrographs. Perhaps one reason this work has not been done is that up until now there has been a lack of tools that can integrate the information into the simulation process. The availability of uncertainty assessment capability in a commonly used and widely available tool such as HEC-HMS will hopefully serve as a catalyst for deeper study on expected or reasonable probability distributions of hydrologic modeling parameters in various regions around the world.

REFERENCES

Panneton, L'Ecuyer, & Matsumoto. (2006). "Improved long-period generators based upon linear resources recurrences modulo 2." *ACM Transactions on Mathematical Software (TOMS)*, vol 32, no 1.