Ensemble Compute Applications in HEC-HMS

Draft extended abstract

Matthew Fleming[1], P.E., Supervisor Civil Engineer, 530-302-3701,
matthew.fleming@usace.army.mil
Gregory Karlovits[1], P.E., P.H., C.F.M., Senior Hydraulic Engineer, 530-302-3698,
gregory.s.karlovits@usace.army.mil
Natalya Sokolovskaya[1], P.E., Civil Engineer (Hydraulics), 323-382-6176,
natalya.l.sokolovskaya@usace.army.mil
Joshua Willis[1], P.E., Civil Engineer (Hydraulics), 530-302-3703,
joshua.r.willis@usace.army.mil

U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616

Introduction

Ensembles represent a way to pool predictions from several models and characterize the uncertainty associated with both the inherent climate variability and model differences. Each base model may include different basin configurations, modeling methods, parameter sets, initial conditions, and/or boundary conditions.

The Hydrologic Modeling System (HEC-HMS) is developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center to simulate the complete hydrologic processes of dendritic watershed systems. One of the new capabilities in software version 4.11 is Ensemble Compute. The new Ensemble Compute feature simplifies the process of obtaining and analyzing ensemble results. This presentation will showcase the new Ensemble feature by first providing an overview of its usage and available documentation, followed by two case study examples: (1) post-fire hydrology forecasting with different precipitation scenarios and (2) hydrologic model with climate prediction data from Coupled Model Intercomparison Project (CMIP 5). The focus of this presentation is to demonstrate the new software feature and discuss some consideration that go into working with long term climate prediction and forecast models. It is not intended as guidance for applying downscaled climate model projections or climate forecasts to inform an analysis.
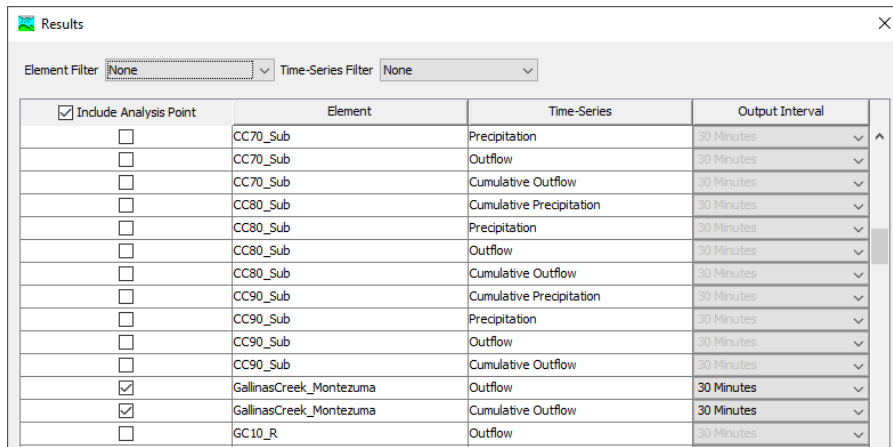
HEC-HMS Ensemble Compute

The new feature allows the modeler to create an Ensemble analysis, where different models (or ensemble members) can be added as shown in Figure 1.
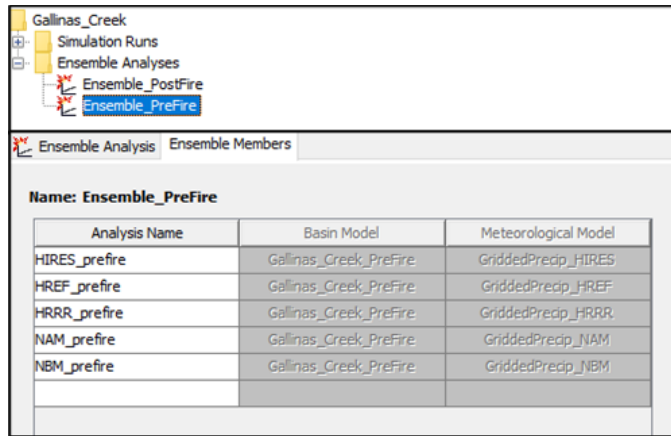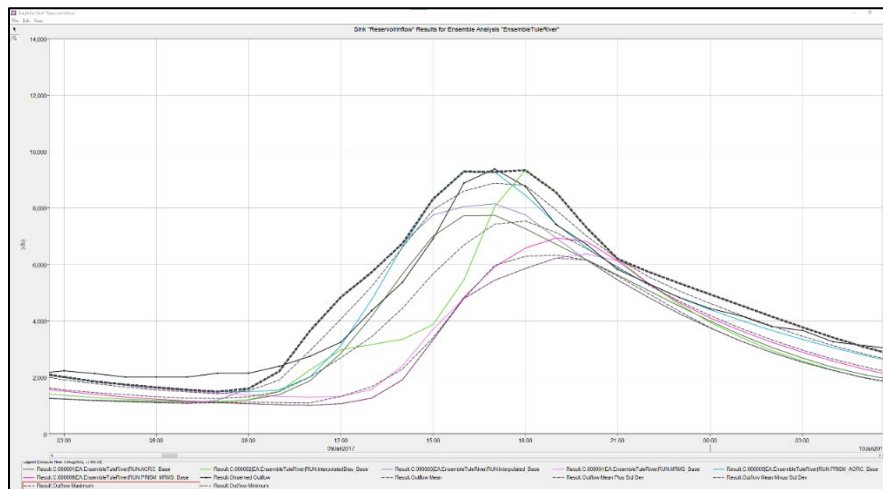
Figure 1. Selecting Ensemble members

The modeler can then select the output time series at the locations of interests (Figure 2) to visualize results and statistics in tables or figures, as illustrated in Figure 3. The results are also exported into a DSS file (database file format incorporated into most of HEC's major application programs).

Figure 2. Output analysis selection

Figure 3. Example of flow hydrograph results from multiple ensemble members

Example 1: Applying Ensemble Compute to Forecasting

In this example, runoff response is predicted with numerical weather forecast models coupled to calibrated hydrology models for the Gallinas Creek watershed in Northern New Mexico. An HEC-HMS model of the upper portion of the Gallinas Creek watershed was created in response to the Calf Canyon / Hermits Peak fires that burned over 300,000 acres in the Sangre de Cristo Mountains. Debris and sediment from the fire scars can cause flooding in the watershed during the monsoon season.

The five NOMAD forecast datasets (Rutledge et al, 2006) selected for this demo are summarized in Table 1 below. Some datasets, like the North American Mesoscale Forecast System (NAM), represent results from a single multidimensional atmospheric model and others, like the National Blend of Model (NBM), include a mean estimate of future precipitation from processing an ensemble of multidimensional atmospheric models.
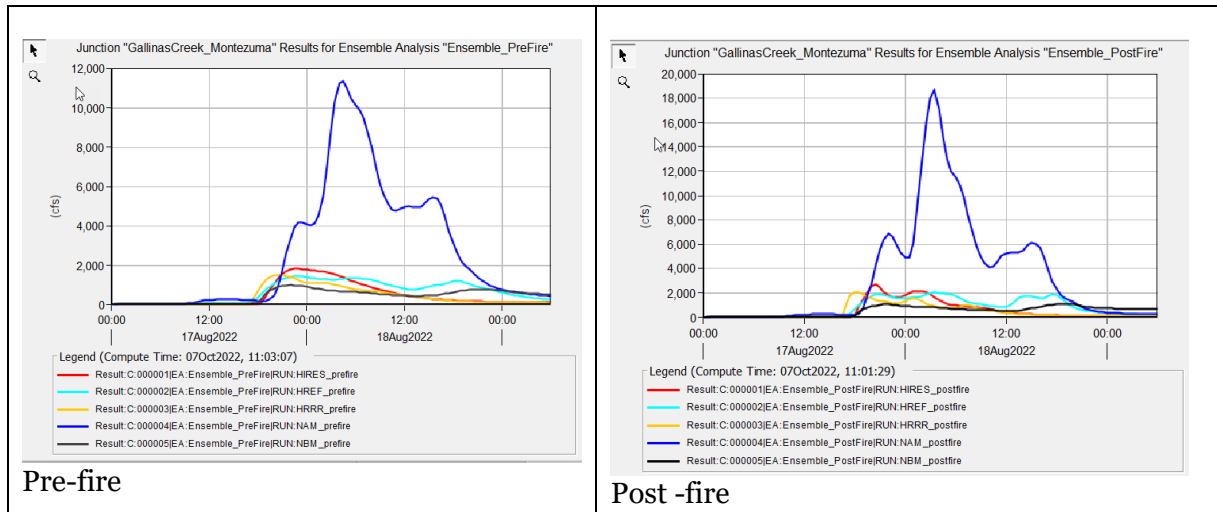
Table 1. Precipitation forecast datasets used in ensemble analysis

Precipitation Product	Link to Product Description
NAM Conus (12km)	https://nomads.ncep.noaa.gov/txt_descriptions/WRF_NMM_doc.shtml
High Resolution Ensemble Forecast (HREF) Mean	https://nomads.ncep.noaa.gov/txt_descriptions/HREF_doc.shtml
HiresWindow (HIRES)	https://nomads.ncep.noaa.gov/txt_descriptions/HIRES_doc.shtml
High-Resolution Rapid Refresh (HRRR)	https://nomads.ncep.noaa.gov/txt_descriptions/HRRR_doc.shtml
National Blend of Models (NBM)	https://nomads.ncep.noaa.gov/txt_descriptions/BLEND_doc.shtml https://vlab.noaa.gov/web/mdl/nbm

Gridded precipitation boundary conditions from each of the five forecast scenarios were combined with two hydrologic models (pre- and postfire). The HEC-HMS models used methods appropriate for rapid estimation of pre and post fire flow and debris/sediment, including the SCS Curve Number, SCS transform, Linear Reservoir baseflow, and Muskingum-Cunge reach routing. The pre-fire hydrologic model was calibrated to an event in 2013 using observed hourly precipitation from the AORC gridded dataset and observed flow at Montezuma USGS gage location, 08380500. The post fire basin model was modified from the pre-fire hydrologic model by adjusting Curve Numbers and SCS lag times to reflect changes to the runoff response due to burned conditions.

The HEC-HMS tutorial (HEC-HMS, 2022a) contains further details on setting up the ensemble computes in HEC-HMS, including on how to download the forecast data with Python scripts, convert it to the HEC-DSS format and link the created *.dss files to grid precipitation datasets to create the corresponding ensemble members.

The modeled flows at the Montezuma gage resulting from the different forecasts for the pre- and post-fire conditions are summarized in Figure 4 below.

Figure 4. Modeled flow hydrograph from forecasted precipitation datasets

The differences between the modeled outflows are driven by the difference in forecasted rainfall, as illustrated for one of the subbasins in Table 2 below.

Table 2. Total time window precipitation depth

Ensemble Member	Precipitation total (in)
HIRES	1.67
HREF	0.33
HRRR	0.85
NAM	3.68
NBM	1.24

Example 2: Applying Ensemble Compute to Downscaled Climate Model Datasets

This Ensemble analysis includes ten of the 35 CMIP5 downscaled climate projection datasets, summarized in Table 3 below. Specifically, the LOCA downscaled CMIP5 Climate Projection datasets (Pierce et al., 2014, 2015) were downloaded from the "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projection" website https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html.

The datasets were gathered for two Representative Concentration Pathways (RCP) climate scenarios, 4.5 and 8.5, reflecting the projected increase in CO_2 concentrations. (Note: this is only an example, an actual study would gather more than five climate datasets.)

**Table 3**. Summary of climate projection datasets used in the model

Climate Model	HEC-HMS Model Data Reference	
	RCP 4.5	RCP 8.5
access1-0	CMIP5-1a	CMIP5-1b
access1-3	CMIP5-2a	CMIP5-2b
bcc-csm1-1	CMIP5-3a	CMIP5-3b
bcc-csm1-1-m	CMIP5-4a	CMIP5-4b
canesm2	CMIP5-5a	CMIP5-5b

The ten temperature and precipitation datasets were input into the calibrated HEC-HMS model for Tule River Basin - a 390 square mile basin above Schafer Dam in Tulare County, CA (HEC-HMS, 2022b). The model was recalibrated to daily average flow (from 1-hour time step in the existing model) using historical Livneh dataset, also obtained from the "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projection" website.

This is a summary of the steps performed in the analysis.
- Download historical Livneh and downscaled CMIP5 climate projection datasets
- Convert historical Livneh and downscaled CMIP5 climate projection datasets to HEC-DSS format
- Create gridsets and time-series gages in the HEC-HMS project
- Create meteorologic models in the HEC-HMS project
- Calibrate the basin model to historical data using daily precipitation and temperature dataset
- Create simulation runs for CMIP5 climate model projection datasets
- Create Ensemble analysis simulations
- Analyze results and identify trends from the Historical Period (1971 - 2005) and Future Period (2006 - 2099)

As an example of the model results, Figure 5 shows average monthly inflow into the Schafer Dam between 1971 and 2099 from one of the ensemble member scenarios – RCP scenario under both 4.5 and 8.5 scenarios. Both RCP scenarios show a shift in the runoff pattern. This pattern shift is most likely due to less snow accumulation. The ensemble analysis provided a useful tool to organize model simulations and results for post processing.
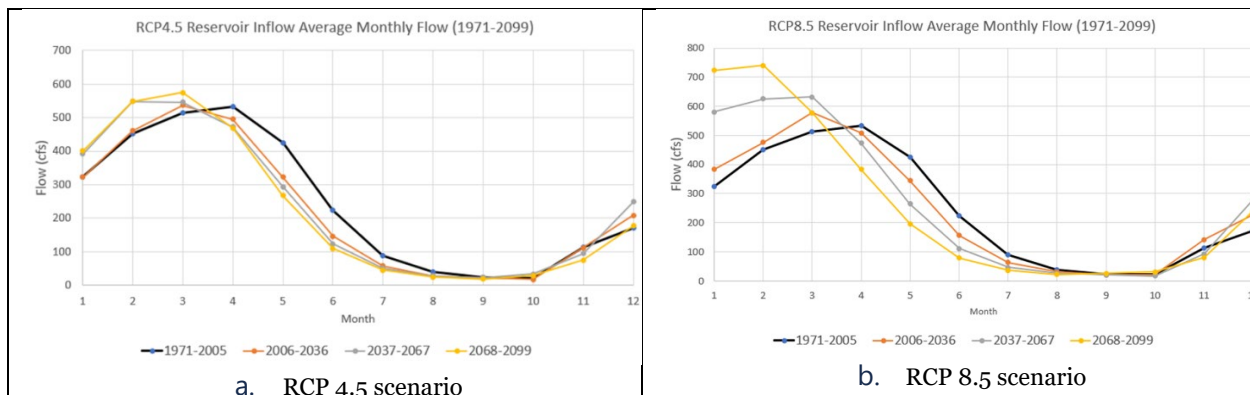
Figure 5. Reservoir inflow monthly average flows under RCP 4.5 (a) and RCP 8.5 (b) scenarios

Acknowledgements

References

HEC-HMS (2022a) HEC-HMS Tutorials and Guides. "Applying the Ensemble Compute to Flood Forecasting".
https://www.hec.usace.army.mil/confluence/display/HMSGUIDES/Applying+the+Ensemble+Compute+to+Flood+Forecasting

HEC-HMS Tutorials and Guides. "Creating an Ensemble Analysis Compute".
https://www.hec.usace.army.mil/confluence/display/HMSGUIDES/Creating+an+Ensemble+Analysis+Compute

Pierce, D. W., D. R. Cayan, and B. L. Thrasher, Statistical Downscaling Using Localized Constructed Analogs (LOCA), *Journal of Hydrometeorology*, 15(6), 2558-2585, 2014.

Pierce, D. W., D. R. Cayan, E. P. Maurer, J. T. Abatzoglou, and K. C. Hegewisch, 2015: Improved bias correction techniques for hydrological simulations of climate change. J. Hydrometeorology, v. 16, p. 2421-2442. DOI: http://dx.doi.org/10.1175/JHM-D-14-0236.1.

Rutledge, G. K., Alpert, J., & Ebisuzaki, W. (2006). NOMADS: A Climate and Weather Model Archive at the National Oceanic and Atmospheric Administration, *Bulletin of the American Meteorological Society*, 87(3), 327-342. Retrieved Dec 13, 2022, from https://journals.ametsoc.org/view/journals/bams/87/3/bams-87-3-327.xml