SENSITIVITY ANALYSIS FOR SEDIMENT TRANSPORT IN THE HYDROLOGIC MODELING SYSTEM (HEC-HMS)

By Jang Pak, Ph.D., P.E.[1], Kervi Ramos[2], Matthew Fleming, P.E.[3], William Scharffenberg, Ph.D.[4], and Stanford Gibson, Ph.D.[5]

[1] Sr. Research Hydraulic Engineer, U.S. Army Corps of Engineers, Institute For Water Resources, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616; PH (530) 756-1104; FAX (530) 756-8250; email: Jay.H.Pak@usace.army.mil.
[2] Student Intern, U.S. Army Corps of Engineers, Institute For Water Resources, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616; email: Kervi.Ramos@usace.army.mil.
[3] Chief, Hydrology & Hydraulics Technology Division, U.S. Army Corps of Engineers, Institute For Water Resources, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616.
[4] HEC-HMS Lead Developer, U.S. Army Corps of Engineers, Institute For Water Resources, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616.
[5] Sr. Research Hydraulic Engineer, U.S. Army Corps of Engineers, Institute For Water Resources, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616.

Abstract

Watershed models are evaluated through calibration and validation processes. However, sediment model parameters and observed data for calibration are often expensive and difficult to collect. Where sediment data is limited, sensitivity analysis can identify the most influential parameters in the model. Identifying sensitive input parameters is critical for model development and application. This paper aims to improve understanding of the sensitivity of the sediment input parameters in the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS 4.0).

Historically, HEC-HMS was focused on modeling rainfall-runoff processes using a full range of components for meteorology, canopy, soil, surface runoff, baseflow, channel routing, reservoirs, and diversions. Recently, components have been added for representing land surface erosion, channel erosion and transport, and lake turbulent settling. A sensitivity analysis evaluated model parameters required by these new sediment capabilities. Sensitivity analysis results were then compared with observed data to identify sensitive parameters and their relative influence. These results can support HEC-HMS sediment model development in locations with little to no observed data.

INTRODUCTION

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) sediment transport module (STM), including surface erosion, in-stream sediment routing, and reservoir sediment routing modeling capabilities was released in December 2013 (USACE 2013). The STM was designed based on applicable knowledge of geomorphology, hydrology, hydraulics, and concepts of surface and sediment transport.

In addition to the implementation of the new STM into HEC-HMS, the HEC-HMS team conducted a detailed sensitivity analysis of the HEC-HMS sediment model to assess the overall influence of sediment input parameters on the computed total cumulated sediment loads. Sensitivity analysis evaluates the relative model response as a function to changes in model input

parameters (Nearing et al. 1990). The evaluation process includes three steps according to Nearing et al. (1990):

- Calibration and validation of the model to measured data
- Sensitivity analysis of the model response to input parameters
- Evaluation of confidence limits for the model prediction

Sensitivity analysis was conducted on selected input parameters of the three main elements (sub-basin, reach, and reservoir) of the HEC-HMS sediment model. The sensitivity analysis used a calibrated and validated HEC-HMS model that consisted of a two-year simulation period (1 January 1995 through 31 December 1996).

HYDROLOGY AND SEDIMENT MODEL OVERVIEW

The study site selected for the sensitivity analysis consists of a 921 km^2 (356 mi^2) watershed called the Upper North Bosque River. The Upper North Bosque River Watershed (UNBRW) is located in Central Texas (Figure 1). UNBRW is a headwater watershed in the North Bosque River basin. Elevation in the watershed ranges from 299 m to 495 m (981 ft to 1624 ft) above sea level. The mean annual precipitation is 750 mm and dominant soil type is fine sandy loams with sandy clay subsoil, calcareous clay, and clay loams in the watershed (Saleh and Du 2004). The HEC-HMS model included 68-subbasin, 40-reservoir, and 84-reach elements based on five gage locations, land use, soil, and topographic information (USACE 2014).

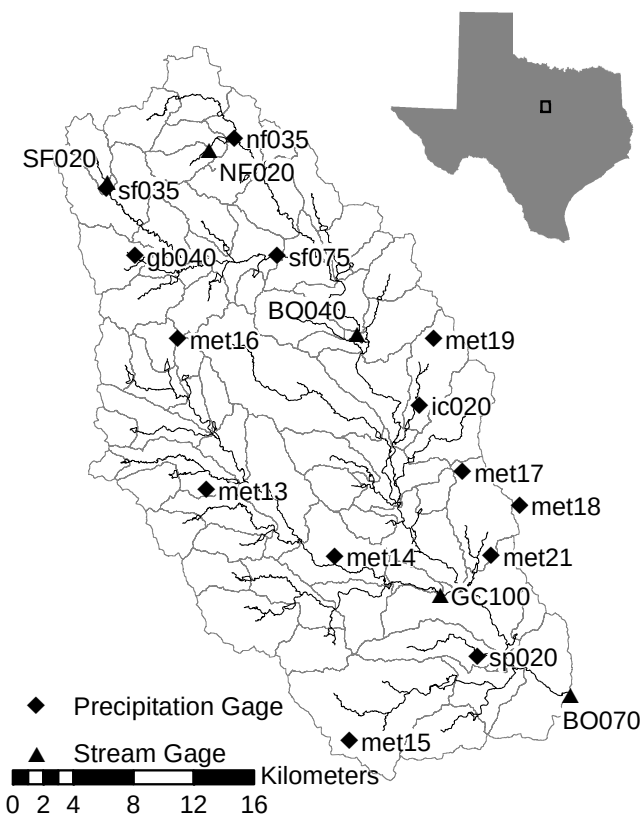

Figure 1 Project Location map including gauged locations for UNBRW

The selection of modeling methods and initial input parameters relied heavily on the data available and appropriateness for hydrology and sediment models. The model was calibrated to observed hydrologic and sediment data from 1 January 1995 to 31 December 1996 by adjusting model parameters to minimize the difference in computed and measured flow and sediment at five gage locations (NF020, SF020, BO040, GC100, and BO070) as shown in Table 1. Unlike the calibration period, the validation of the model required observed data from 1 January 1997 to 31 December 1998 (USACE 2014). Using the calibrated and validated hydrology/sediment model, a sensitivity analysis was conducted by changing one of the selected sediment model parameters or methods and fixing others as based values during the calibration period.

Table 1 Measured and computed results of daily flow and TSS loading.

		Calibration Period (01Jan1995 to 31Dec1996)					
		Hydrology (ft^3/s)			Sediment (tons)		
		Mean	Standard Deviation	Mean Error	Mean	Standard Deviation	Mean Error
NF020	Measured	1.06	4.94	N/A	2.66	23.12	N/A
	HMS	1.41	6.36	0.35	2.67	32.24	0.01
SF020	Measured	1.41	7.77	N/A	1.32	15.00	N/A
	HMS	1.77	9.89	0.35	1.32	12.79	-0.01
BO40	Measured	33.90	99.23	N/A	24.68	190.17	N/A
	HMS	32.49	123.95	-1.06	24.61	180.16	-0.07
GC100	Measured	30.72	92.88	N/A	1.32	15.00	N/A
	HMS	31.43	127.49	0.71	22.74	181.57	0.07
BO070	Measured	102.06	303.00	N/A	99.69	799.16	N/A
	HMS	108.06	423.07	6.00	100.03	890.15	0.33

METHODOLOGY

A linear sensitivity model was selected for sensitivity testing of HEC-HMS sediment model. The sensitivity parameter (S) is computed using equation (1).

$$S = \frac{\left(\dfrac{O_2 - O_1}{O_{12}}\right)}{\left(\dfrac{I_2 - I_1}{I_{12}}\right)} \tag{1}$$

Where;
I_1: the least value of input parameter
I_2: the greatest value of input parameter
I_{12}: the average value of I_1 and I_2
O_1: the output value of I_1
O_2: the output value of I_2
O_{12}: the average value of O_1 and O_2

The dimensionless sensitivity parameter (S) quantifies the sensitivity of the input parameter by comparing the relative normalized output change to a normalized input change. McCuen and

Snyder (1983) discuss limitations of the linear sensitivity analysis used in this paper. One of the biggest limitations of the linear sensitivity equation (1) above is that, equation 1 yields a single sensitivity parameter value instead of a distribution of outputs as a function of the input parameter distribution. Describing the sensitivity parameter as a distribution instead of a single value will better describe sensitivity of the parameters.

In this sensitivity analysis, wide ranges of input parameters were selected for the subbasin, reach, and reservoir elements (Table 2). Generally, one selected parameter was varied and other parameters were fixed as base values.

Table 2 Parameters and method selected for Sensitivity Analysis

Element	**Parameter/Method**
Subbasin Element	Enrichment Ratio
	Sand
	Silt
	Clay
	MUSLE (Cover Factor)
Reach Element	Fraction of Gravel
	Channel Width
	Active Layer Factor
Reservoir Element	Fall Velocity Method

SENTIVITY TO SEDIMENT METHODS AND PARAMETERS

The particle size distribution of source material in the subbasin (on the land surface) is generally much coarser than the stream channel sediment at the basin outlet due to changing hydrodynamic forces as water flows over the land surface and concentrates within streams and channels. The clay and silt enrichment in the suspended sediment is largely the result of preferential deposition of the courser fraction during the transport and delivery of sediment from its source to basin outlet (USACE 2014). The enrichment ratios for each particle class converted the watershed particle-size distribution to an outlet particle-size distribution: The enrichment ratio is defined in equation (2) below.

$$ER = \frac{\%\ sediment\ in\ a\ given\ size\ class\ in\ outlet}{\%\ sediment\ in\ a\ given\ size\ class\ in\ watershed} \tag{2}$$

Where, ER is the enrichment ratio. The numerator, % sediment in a given size class at the outlet, can be determined from a suspended sediment sample near the subbasin outlet. The denominator, % sediment in a given size class in watershed, comes from the SSURGO soil data. The ER was a calibration factor in the original model.

The ERs were computed by varying enrichment ratios ~ ±15% from calibrated values, for each grain class (sand, silt and clay) while fixing the base values for other parameters. The differences of sediment yields from calibrated model results, at each computation point are shown in Figures 2 through 4 for sand, silt, and clay respectively.

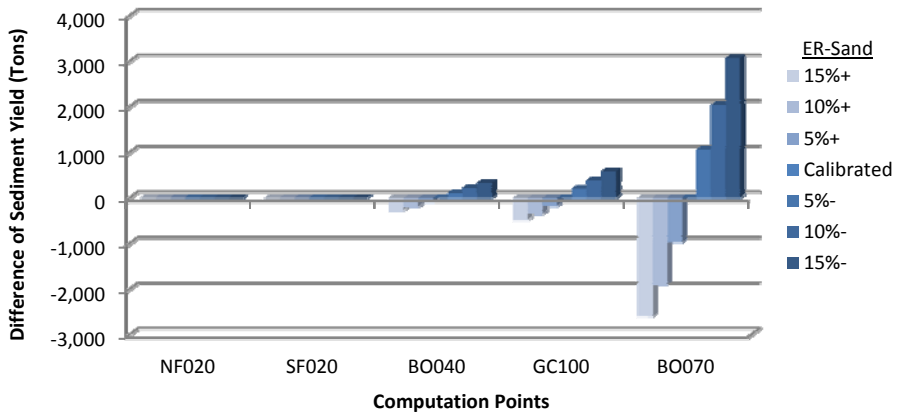

Figure 2 Impact of six selected enrichment ratios of sand on simulated sediment yield for the calibration period (1 January 1995 through 31 December 1996)

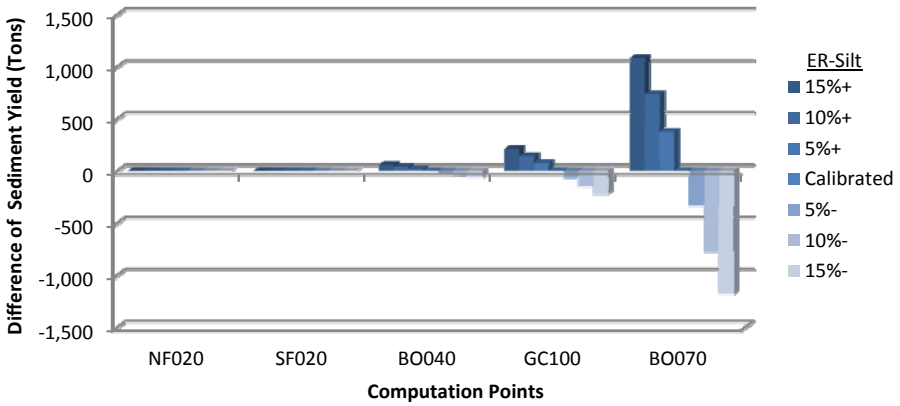

Figure 3 Impact of six selected enrichment ratios of silt on simulated sediment yield for the calibration period (1 January 1995 through 31 December 1996)

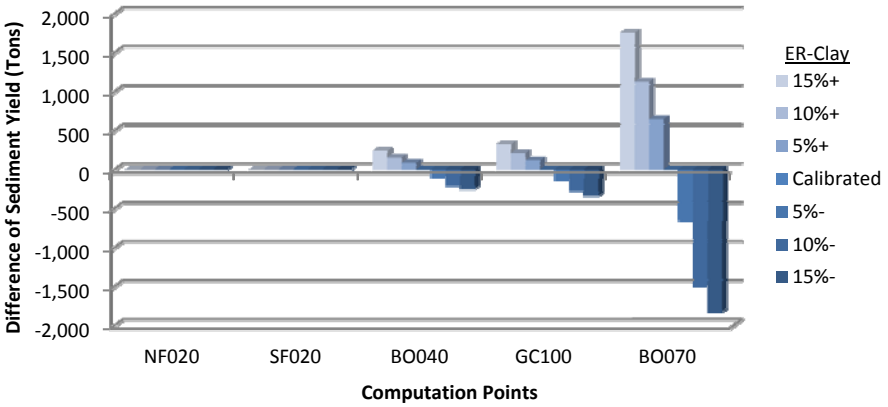

Figure 4 Impact of six selected enrichment ratios of clay on simulated sediment yield for the calibration period (1 January 1995 through 31 December 1996)

MUSLE cover factor sensitivity was determined by varying the cover factor ~ ±50%, relative to the calibrated parameter. The simulation results, in terms of the differences of sediment yields from calibrated model results at each computation point, are shown in Figure 5.

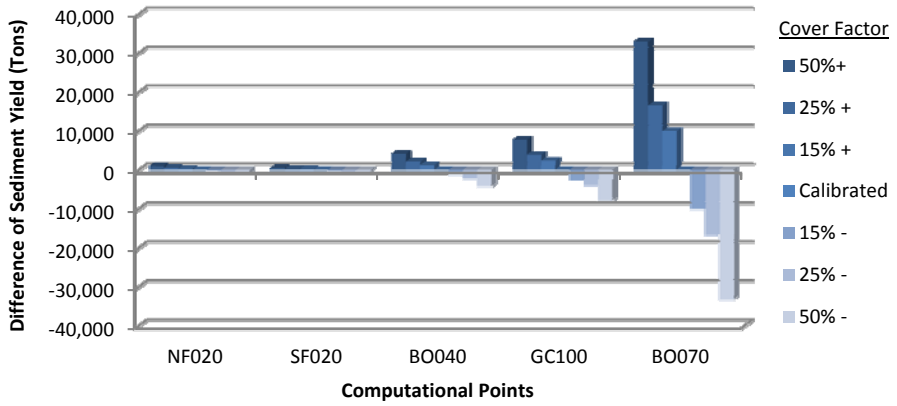

Figure 5 Impact of six selected MUSLE cover factors on simulated sediment yield for the calibration period (1 January 1995 through 31 December 1996)

Sensitivities to the fraction of gravel in the channel bed were determined by varying the gravel fraction from -1% to ~ -25% of the calibrated model parameter, using fixed base values for other parameters. The differences of sediment yields from calibrated model results for these simulations, at each computation point are shown in Figure 6.

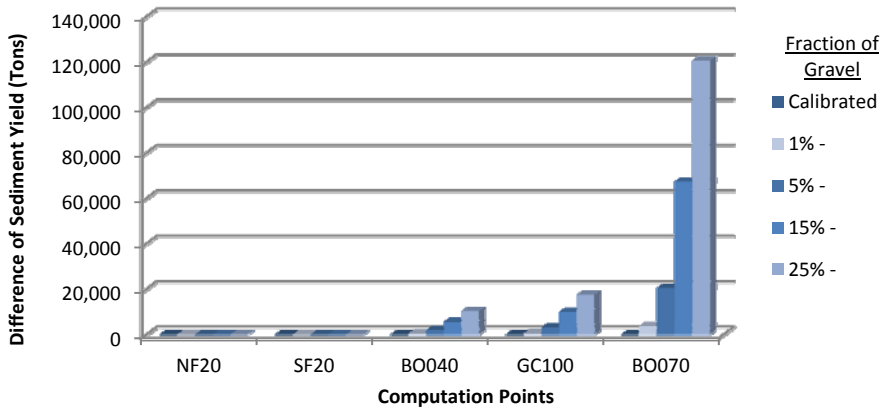

Figure 6 Impact of four selected fraction of gravel for channel gradation simulated sediment yield for the calibration period (1 January 1995 through 31 December 1996)

The channel bed widths were adjusted ~±50% of the calibrated values to test sensitivity to this routing parameter. Simulation results at each computation point are included in Figure 7.

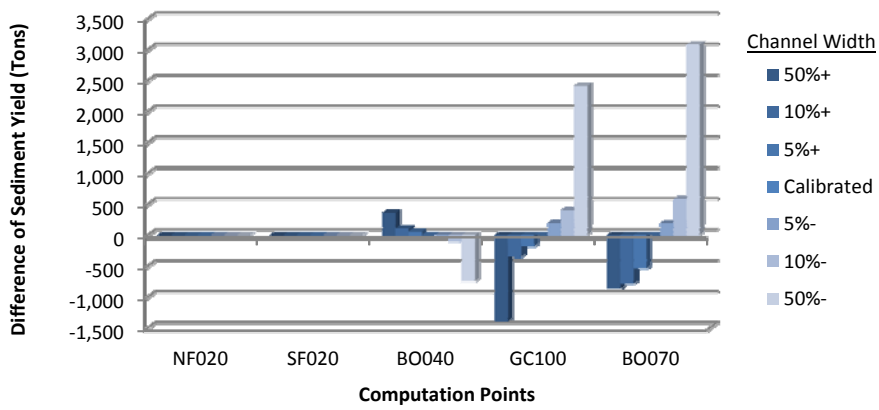

Figure 7 Impact of six selected widths of channel on simulated sediment yield for the calibration period (1 January 1995 through 31 December 1996)

Active layer factor (the thickness of the reach element active layer in multiples of d_{90}) was adjusted from 1 to 3, bracketing the calibrated value of 2. As with the other analyses, the calibration parameters were fixed for all other model variables. Simulation results, in terms of the differences of sediment yields from calibrated model results at each computation point, are shown in Figure 8. Stations NF20 and SF20 results are not sensitive to channel width, gravel content, or active layer thickness because these are directly downstream of a specific subbasin element. There are no reach elements upstream of them for the routing parameters to influence the results.

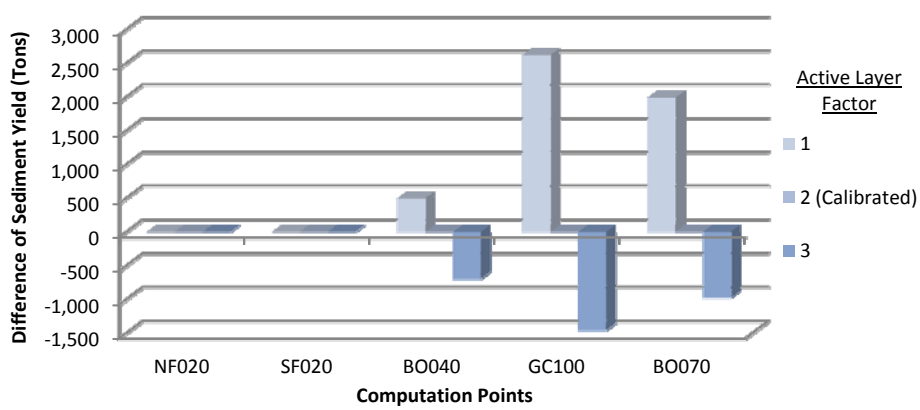

Figure 8 Impact of two selected active layer factors on simulated sediment yield for the calibration period (1 January 1995 through 31 December 1996)

Reservoir fall velocity method sensitivity was evaluated by running the model with all four options available. Results at each computation point are included in Figure 9.

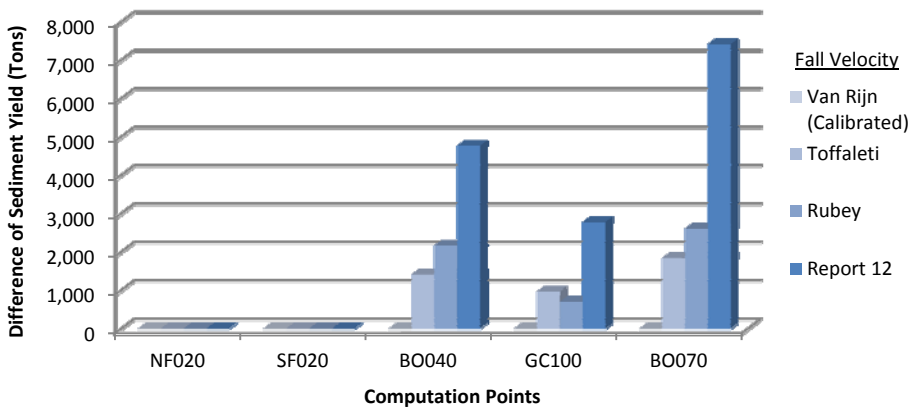

Figure 9 Impact of three selected fall velocity methods on simulated sediment yield for the calibration period (1 January 1995 through 31 December 1996)

RESULTS OF SENSITIVITY ANALYSIS

The parameters tested are listed in Table 3 and include units, base values from calibration, input values, and calculated sensitivity parameter (S) values and rank. Input 1 and Input 2 are the minimum and maximum values, respectively, from the sensitivity analysis. Total accumulated sediment yield was most sensitive to the channel gravel fraction for reach elements and the other two channel parameters (channel width and active layer thickness) were relatively insensitive. The MUSLE cover factor and Sand Enrichment Ratio were sensitive parameters for the subbasin elements. The fall velocity method (especially, Report 12) for the reservoir elements also had some influence on the outlet sediment yields.

Table 3 Summary of Sediment Model Parameters and method used for Sensitivity Analysis

Parameters	Units	Base	Input 1	Input 2	(S)	Rank
Subbasin Element						
Enrichment Ratio[1]						
Sand	Unitless	57.97	54.35	61.04	-0.67	3
Silt	Unitless	29.92	26.69	32.86	0.15	5
Clay	Unitless	12.12	10.55	13.62	0.19	4
MUSLE (Cover Factor) [1]	Unitless	0.011	0.005	0.016	0.91	2
Reach Element						
Fraction of Gravel[2]	Unitless	0.92	0.69	0.91	-3.13	1
Channel Width[2]	(ft)	30.90	15.50	46.40	-0.05	6
Active Layer	Unitless	2.00	1.00	3.00	-0.04	7

[1] – The area weighted average values were used to calculate the sensitivity parameter (S).
[2] – The length weighted average values were used to calculate the sensitivity parameter (S).

SUMMARY AND CONCLUSIONS

This paper presents a sensitivity analysis of the new sediment transport module available in HEC-HMS Version 4.0. The new sediment modeling tool allows the use of HEC-HMS for the assessment of watershed sediment transport. Eight sensitivity tests were developed to evaluate the HEC-HMS watershed sediment model parameters and identify those particularly important to calibrate a sediment model.

The output from an HEC-HMS model with a single perturbed parameter was compared to the calibrated model. This sensitivity analysis indicates the level of sensitivity for each selected parameters and provides guidance to modelers developing watershed surface erosion models with little to no observe data. While this work can inform other studies, sensitivity analysis can be site specific and sensitive parameters in other watersheds may diverge from those identified in the UNBRW study area.

REFERENCES

McCuen, R. H., and W. M. Snyder. (1993). Hydrologic Modeling: Statistical Methods and Applications. Englewood Cliffs, N.J.: Prentice-Hall.

Nearing, M. A., L. Deer-Ascough, and J.M. Laflen. (1990). "Sensitivity Analysis Of The WEEP Hillslope Profile Erosion Model." Transactions of the ASAE, 33(3): 839-849.

Saleh, A., and Du, B. (2004). "Evaluation Of SWAT And HSPF Within Basins Program For The Upper North Bosque River Watershed In Central Texas." Transactions of the ASAE, 47(4): 1039-1049.

U. S. Army Corps of Engineers. (2013). Hydrologic Modeling System HEC-HMS: User's Manual. Hydrologic Engineering Center, Davis, CA.

U. S. Army Corps of Engineers. (2014). Hydrologic Modeling System HEC-HMS: Applications Guide. Hydrologic Engineering Center, Davis, CA.