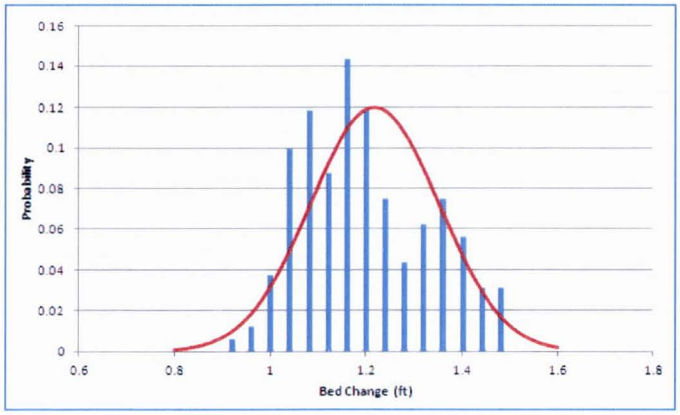
DEVELOPMENT AND EVALUATION OF THE

MONTE CARLO SEDIMENT SIMULATION TOOL (MCSED.XLSM)

Final deliverable (1 of 2) of *Technical Support and Engineering Solutions*

FCD 2010C027, Assignments 11 and 13



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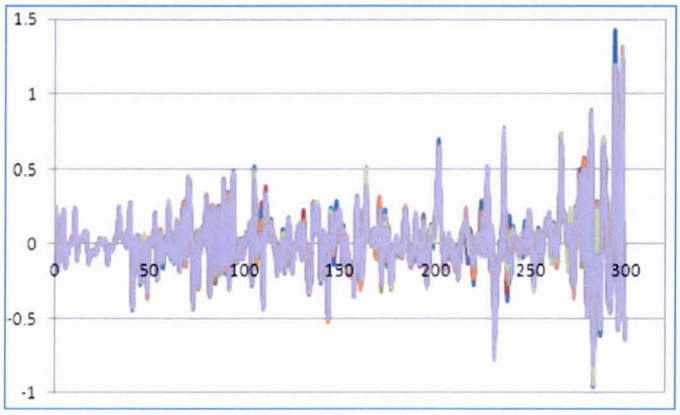

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Preface

This report was extracted from the original comprehensive report that tested both MCSED.XLSM and GPMT.XLSM. It is specific to the MCSED portion only; the companion report consists of the GPMT portion. Submitted in September of 2012, the original report was titled:

DEVELOPMENT AND EVALUATION OF TWO WORKBOOKS:
MONTE CARLO SEDIMENT SIMULATION TOOL (MCSED.XLSM)
GRAVEL PIT MINING TOOL (GPMT.XLSM)

Final deliverable of *Technical Support and Engineering Solutions*
FCD 2010C027, Assignments 11 and 13

Some edits were made to the original MCSED section in order to make this report standalone. In all other ways, the text herein is identical to the corresponding sections in the original report.

Introduction

Overview

By request of the Flood Control District of Maricopa County (FCDMC), WEST Consultants, Inc. (WEST) has developed two Excel workbooks designed to facilitate the use of HEC-6 and HEC-6T models. The first of these two workbooks is the Gravel Pit Mining Tool (GPMT.xlsm), which is specific to analyzing, developing, optimizing, and reviewing proposed gravel pit construction projects. The second is the Monte Carlo Sediment Simulation Tool (MCSed.xlsm) which utilizes the Monte Carlo technique to perform uncertainty analyses of developed HEC-6T models.

This report is an extraction of the MCSED specific text in the originally submitted and approved as a single comprehensive report covering both the GPMT and MCSED. As such, some of the text has been changed to refer to the MCSED portion only. In all other ways this report is identical to the corresponding sections of the original.

This report documents the algorithms used, features in, beta testing, and limitations of MCSED. The intent of this report is meet all of the documentation requirements specified in as Assignments 11 and 13, *Technical Support and Engineering Solutions*, tasks given under contract FCD 2010C027, specific to MCSED. In particular, the sections of the report describing the beta testing procedures and results were written specifically to meet the requirements of the final deliverable sub-tasks detailed in Assignment 13.

This project effort was directed by two personnel with FCDMC: Dr. Bing Zhao with technical guidance and quality control provided by Dr. J. Rafael Pacheco. From WEST, Dr. Brian Wahlin managed the project; Mr. Chris Goodell took the primary role for researching, developing, and documenting MCSed.xlsm.

Model Description

MCSed was developed by WEST Consultants for the Flood Control District of Maricopa County under Contract 2010C027 Assignment #11. The objective of MCSed is to allow water resources engineers at the FCDMC to evaluate sedimentation in rivers and streams under a probabilistic scenario, allowing for risk-based evaluations of alternatives. This objective is achieved by implementing a Monte Carlo simulation program which executes HEC-6T programs from Excel and imports the results.

Testing

PROJECT FILE

MCSed.xlsm was beta tested utilized the existing HEC-6T model for Centennial Wash, developed by WEST Consultants in November of 2000 for the El Paso Natural Gas Company . The original .T5 (input) files were modified to establish one file that considered the 100-year flood only. A copy of this model (100YR.T5) may be found in Appendix A.

METHODOLOGY

Three independent Design of Computer Experiment (DOCE) testing schemes were developed to test MCSed: Approach Sensitivity, Mannings Sensitivity, and Realization Number Sensitivity. These three experiments are described in the following subsections.

Approach Sensitivity

MCSed.xlsm allows two different statistical distributions to be considered for each of the input factors; these being Mannings *n*; D_{50} (the median grain size diameter) Streamflow; and Sediment Influx. The first distribution available for each factor is the 'Literature Supported Distribution', corresponding to the distribution best supported by the most up to date literature research (see Appendix B). The second option is the triangular distribution, which was included in recognition that the actual statistical distributions for the different parameters are still not well understood and may not apply to all applications. Accordingly, for some applications it may be most appropriate to use the simple triangular distribution since its simplicity is arguably proportional to the degree of knowledge.

The Approach Sensitivity DOCE followed the scheme shown in Table 1 below. Specifically, 100 replications were included for each of the possible distribution selection combinations. A full two level factorial experiment (2^4) was conducted with a 10% standard deviation assumed for all distributions. In total, 1,600 replications were made for each of the 20 cross-sections. A repeated measures MANOVA analysis was used for the analysis (hence 'Cross-section number' was accounted for but blocked for the hypothesis testing). Two response variables were considered: Maximum Scour and Maximum Deposition. Sediment trap efficiency, which is evaluated only at the final cross-section, had to be considered separately, and so was analyzed as a Repeated Measures ANOVA. The literature supported distributions were coded as '1'; the triangular distributions were coded as '2'.

Table 1. Approach Sensitivity Experimental Design

	Statistical Distribution Selection				
Experiment	**Manning's**	**D_{50}**	**Streamflow**	**Sediment**	**Number of Replications**
1	Triangular	Triangular	Triangular	Triangular	100
2	Lognormal	Triangular	Triangular	Triangular	100
3	Triangular	Uniform	Triangular	Triangular	100
4	Lognormal	Uniform	Triangular	Triangular	100
5	Triangular	Triangular	Lognormal	Triangular	100
6	Lognormal	Triangular	Lognormal	Triangular	100
7	Triangular	Uniform	Lognormal	Triangular	100
8	Lognormal	Uniform	Lognormal	Triangular	100
9	Triangular	Triangular	Triangular	Lognormal	100
10	Lognormal	Triangular	Triangular	Lognormal	100
11	Triangular	Uniform	Triangular	Lognormal	100
12	Lognormal	Uniform	Triangular	Lognormal	100
13	Triangular	Triangular	Lognormal	Lognormal	100
14	Lognormal	Triangular	Lognormal	Lognormal	100
15	Triangular	Uniform	Lognormal	Lognormal	100
16	Lognormal	Uniform	Lognormal	Lognormal	100

Mannings Sensitivity

Mannings *n*-values are considered within MCSed in two different ways: statistical distribution approach (Lognormal or Triangular) and randomization level. The randomization level refers to the choice that the user must make before executing the program. These options and how they were coded are as follows:

1. Randomize every *n*-value encountered;
2. Randomize all the *n*-values in a given record (typically the NV card) proportionally to the same randomly generated number;
3. Randomize all of the *n*-values in the entire file proportionally to just one randomly generated number.

To investigate the effects of these choices, another factorial experiment was conducted. In this case, the experiment design is a mixed factorial ($2^1 3^1$), with two choices for Manning's *n* distribution (Lognormal or Triangular, coded 1 and 2 respectively) and the three choices for randomization level noted above (Once per instance; Once per record; Once per file; coded 1, 2, and 3 respectively). The dependent variables were Maximum Scour, Maximum Deposition, and Trap Efficiency. Like the Approach Sensitivity test, the Maximum Scour and Maximum Deposition results were analyzed by MANOVA; Trap Efficiency was analyzed by ANOVA. The design is shown in Table 2.

Table 2. Mannings Sensitivity Experimental Design

Experiment	Manning's Distribution	Manning's Randomization Scheme	Number of Replications
1	Lognormal	Once per Instance	100
2	Lognormal	Once per Record	100
3	Lognormal	Once per File	100
4	Triangular	Once per Instance	100
5	Triangular	Once per Record	100
6	Triangular	Once per File	100

Realization Number Sensitivity

One difficult value to select when executing a Monte Carlo simulation is the total number of realizations. This choice as specific to MCSed was investigated by comparing the results of the base simulation given 10, 30, 100, 300, 1000, 3000, and 10000 simulations. No hypothesis testing was conducted.

TESTING RESULTS

Approach Sensitivity

Following generation of the replicates, a full MANOVA of the Maximum Scour and Maximum Deposition results were conducted within Minitab Release 14 (Minitab, 2006). The results, shown in Table 3, indicated that *Mannings* and *Streamflow* distribution choices were significant factors ($p < 0.05$); and that the cross-factors *Mannings* × *Streamflow*, D_{50} × *Sediment*, and *Mannings* × *Streamflow* × *Sediment* were borderline significant ($0.05 < p < 0.10$).

Table 3. Approach Sensitivity MANOVA Results

Factor	s	m	n	Criterion	Test Statistic	F	DF Num	DF Denom	P
X-Section (blocked)	*2*	*8.5*	*16781*	*Wilks'*	*0.60475*	*479.804*	*40*	*67126*	*0.000*
				Lawley-Hotelling	*0.57571*	*483.049*	*40*	*67124*	*0.000*
				Pillai's	*0.44234*	*476.564*	*40*	*67128*	*0.000*
				Roy's	*0.35855*				
Mannings	**1**	**0**	**16781**	**Wilks'**	**0.99481**	**87.533**	**2**	**33563**	**0.000**
				Lawley-Hotelling	**0.00522**	**87.533**	**2**	**33563**	**0.000**
				Pillai's	**0.00519**	**87.533**	**2**	**33563**	**0.000**
				Roy's	**0.00522**				
D50	1	0	16781	Wilks'	0.99997	0.536	2	33563	0.585
				Lawley-Hotelling	0.00003	0.536	2	33563	0.585
				Pillai's	0.00003	0.536	2	33563	0.585
				Roy's	0.00003				
Streamflow	**1**	**0**	**16781**	**Wilks'**	**0.99976**	**3.968**	**2**	**33563**	**0.019**
				Lawley-Hotelling	**0.00024**	**3.968**	**2**	**33563**	**0.019**
				Pillai's	**0.00024**	**3.968**	**2**	**33563**	**0.019**
				Roy's	**0.00024**				
Sediment	1	0	16781	Wilks'	1.00000	0.036	2	33563	0.964
				Lawley-Hotelling	0.00000	0.036	2	33563	0.964
				Pillai's	0.00000	0.036	2	33563	0.964
				Roy's	0.00000				
Mannings × D50	1	0	16781	Wilks'	0.99989	1.850	2	33563	0.157
				Lawley-Hotelling	0.00011	1.850	2	33563	0.157
				Pillai's	0.00011	1.850	2	33563	0.157
				Roy's	0.00011				
Mannings × Streamflow	***1***	***0***	***16781***	***Wilks'***	***0.99985***	***2.582***	***2***	***33563***	***0.076***
				Lawley-Hotelling	***0.00015***	***2.582***	***2***	***33563***	***0.076***
				Pillai's	***0.00015***	***2.582***	***2***	***33563***	***0.076***
				Roy's	***0.00015***				
Mannings × Sediment	1	0	16781	Wilks'	0.99996	0.641	2	33563	0.527
				Lawley-Hotelling	0.00004	0.641	2	33563	0.527
				Pillai's	0.00004	0.641	2	33563	0.527
				Roy's	0.00004				
D50 × Streamflow	1	0	16781	Wilks'	0.99993	1.234	2	33563	0.291
				Lawley-Hotelling	0.00007	1.234	2	33563	0.291
				Pillai's	0.00007	1.234	2	33563	0.291
				Roy's	0.00007				
D50 × Sediment	***1***	***0***	***16781***	***Wilks'***	***0.99986***	***2.380***	***2***	***33563***	***0.093***
				Lawley-Hotelling	***0.00014***	***2.380***	***2***	***33563***	***0.093***
				Pillai's	***0.00014***	***2.380***	***2***	***33563***	***0.093***

Factor	s	m	n	Criterion	Test Statistic	F	DF Num	DF Denom	P
				Roy's	***0.00014***				
Streamflow × Sediment	1	0	16781	Wilks'	0.99999	0.217	2	33563	0.805
				Lawley-Hotelling	0.00001	0.217	2	33563	0.805
				Pillai's	0.00001	0.217	2	33563	0.805
				Roy's	0.00001				
Mannings × D50 × Streamflow	1	0	16781	Wilks'	0.99989	1.899	2	33563	0.150
				Lawley-Hotelling	0.00011	1.899	2	33563	0.150
				Pillai's	0.00011	1.899	2	33563	0.150
				Roy's	0.00011				
Mannings × D50 × Sediment	1	0	16781	Wilks'	0.99991	1.593	2	33563	0.203
				Lawley-Hotelling	0.00009	1.593	2	33563	0.203
				Pillai's	0.00009	1.593	2	33563	0.203
				Roy's	0.00009				
Mannings × Streamflow × Sediment	***1***	***0***	***16781***	***Wilks'***	***0.99983***	***2.862***	***2***	***33563***	***0.057***
				Lawley-Hotelling	***0.00017***	***2.862***	***2***	***33563***	***0.057***
				Pillai's	***0.00017***	***2.862***	***2***	***33563***	***0.057***
				Roy's	***0.00017***				
D50 × Streamflow × Sediment	1	0	16781	Wilks'	0.99992	1.412	2	33563	0.244
				Lawley-Hotelling	0.00008	1.412	2	33563	0.244
				Pillai's	0.00008	1.412	2	33563	0.244
				Roy's	0.00008				
D50 × Streamflow × Sediment	1	0	16781	Wilks'	0.99995	0.893	2	33563	0.409
				Lawley-Hotelling	0.00005	0.893	2	33563	0.409
				Pillai's	0.00005	0.893	2	33563	0.409
				Roy's	0.00005				

With the overall MANOVA results indicating significant relationships between the outcomes and at least one combination of all of the factors, individual ANOVA tests were conducted on the two dependent variables. The ANOVA results for Trap Efficiency Approach are shown in Figure 1 and Table 1. Two main effects were found to be significant at $p < 0.05$: *Mannings* and *Streamflow*. The three term cross-factor effect *Mannings × D50 × Sediment* was also significant at $p < 0.05$ In addition, three cross-factor effects were borderline significant at $0.05 < p < 0.10$: *Mannings × Streamflow*; *Streamflow × Sediment*; and the full cross-factor interaction term *Mannings × D50 × Streamflow × Sediment*.

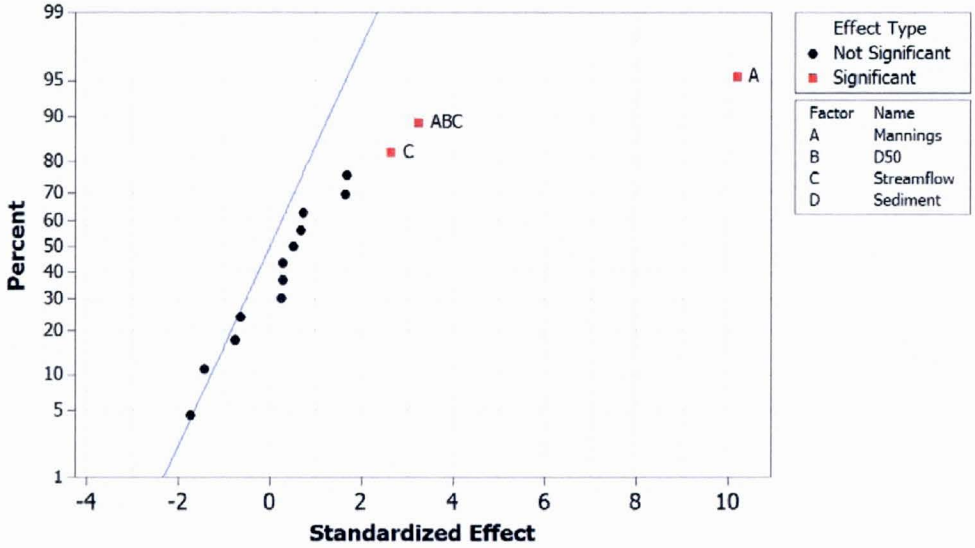

Figure 1. Trap Efficiency Approach Normal Probability Plot of the Standardized Effects

Table 4. Trap Efficiency Approach ANOVA Results

Source	DF	SS	MS	F	P
Mannings	1	0.147968	0.147968	103.81	0.000
D50	1	0.000578	0.000578	0.41	0.524
Streamflow	1	0.009940	0.009940	6.97	0.008
Sediment	1	0.000800	0.000800	0.56	0.454
Mannings*D50	1	0.000760	0.000760	0.53	0.465
Mannings*Streamflow	1	0.003872	0.003872	2.72	0.099
Mannings*Sediment	1	0.000112	0.000112	0.08	0.779
D50*Streamflow	1	0.002888	0.002888	2.03	0.155
D50*Sediment	1	0.000364	0.000364	0.26	0.613
Streamflow*Sediment	1	0.004050	0.004050	2.84	0.092
Mannings*D50*Streamflow	1	0.014965	0.014965	10.50	0.001
Mannings*D50*Sediment	1	0.000648	0.000648	0.45	0.500
Mannings*Streamflow*Sediment	1	0.000085	0.000085	0.06	0.808
D50*Streamflow*Sediment	1	0.000113	0.000113	0.08	0.779
Mannings*D50*Streamflow*Sediment	1	0.004232	0.004232	2.97	0.085
Error	3184	4.538460	0.001425		
Total	3199	4.729835			

S = 0.0377544 R-Sq = 4.05% R-Sq(adj) = 3.59%

The ANOVA results for MCSed Maximum Scour are shown in Figure 2 and Table 5. Two main effects are significant at $p < 0.05$: *Mannings* and *Streamflow*. Two cross-factor effects are also significant at $p < 0.05$: *Mannings* × *Streamflow* and *Mannings* × *Streamflow* × *Sediment*. Finally, the cross-factor effect *D50* × *Streamflow* × *Sediment* is borderline significant at $0.05 < p < 0.10$.

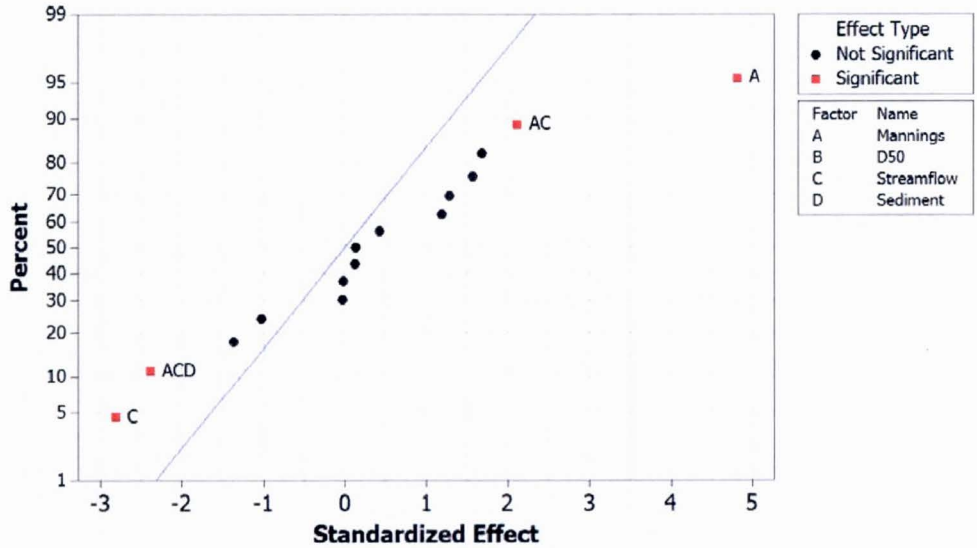

Figure 2. Maximum Scour Approach Normal Probability Plot of the Standardized Effects

Table 5. Maximum Scour Approach ANOVA Results

Source	DF	SS	MS	F	P
X-Section (blocked)	*20*	*10573.96*	*528.70*	*433.18*	*0.000*
Mannings	**1**	**28.28**	**28.28**	**23.17**	**0.000**
D50	1	1.30	1.30	1.06	0.303
Streamflow	**1**	**9.67**	**9.67**	**7.92**	**0.005**
Sediment	1	0.02	0.02	0.01	0.903
Mannings*D50	1	1.71	1.71	1.40	0.236
Mannings*Streamflow	**1**	**5.47**	**5.47**	**4.48**	**0.034**
Mannings*Sediment	1	0.22	0.22	0.18	0.671
D50*Streamflow	1	3.01	3.01	2.46	0.117
D50*Sediment	1	0.00	0.00	0.00	0.976
Streamflow*Sediment	1	0.00	0.00	0.00	0.987
Mannings*D50*Streamflow	1	2.27	2.27	1.86	0.173
Mannings*D50*Sediment	1	0.02	0.02	0.02	0.895
Mannings*Streamflow*Sediment	**1**	**6.96**	**6.96**	**5.70**	**0.017**
D50*Streamflow*Sediment	**1**	**3.43**	**3.43**	**2.81**	**0.094**
Mannings*D50*Streamflow*Sediment	1	2.00	2.00	1.64	0.201
Error	33564	40964.75	1.22		
Total	33599	51603.06			

S = 1.10476 R-Sq = 20.62% R-Sq(adj) = 20.53%

Likewise, the ANOVA results for MCSed Maximum Deposition are shown in Figure 3 and Table 6. The main effect *Mannings* and the cross-factor effect *D50 × Sediment* are both significant at $p < 0.05$. The *Mannings × D50 × Sediment* cross-factor effect is borderline significant at $0.05 < p < 0.10$.

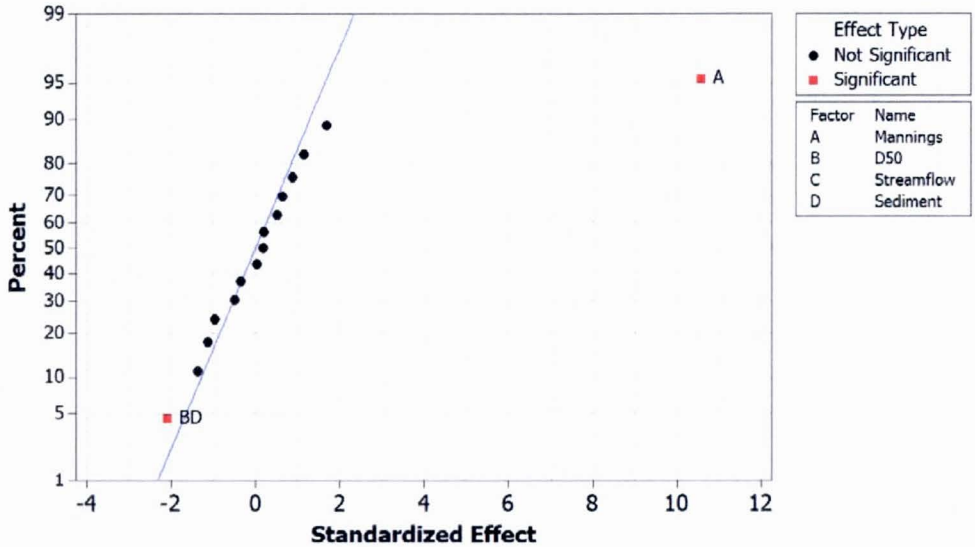

Figure 3. Maximum Deposition Approach Normal Probability Plot of the Standardized Effects

Table 6. Maximum Deposition Approach ANOVA Results

Source	DF	SS	MS	F	P
X-Section (Blocked)	*20*	*2267.204*	*113.360*	*470.00*	*0.000*
Mannings	**1**	**26.981**	**26.981**	**111.86**	**0.000**
D50	1	0.008	0.008	0.03	0.855
Streamflow	1	0.183	0.183	0.76	0.384
Sediment	1	0.010	0.010	0.04	0.842
Mannings*D50	1	0.314	0.314	1.30	0.254
Mannings*Streamflow	1	0.449	0.449	1.86	0.172
Mannings*Sediment	1	0.305	0.305	1.26	0.261
D50*Streamflow	1	0.058	0.058	0.24	0.623
D50*Sediment	**1**	**1.056**	**1.056**	**4.38**	**0.036**
Streamflow*Sediment	1	0.098	0.098	0.41	0.523
Mannings*D50*Streamflow	1	0.230	0.230	0.95	0.329
Mannings*D50*Sediment	**1**	**0.680**	**0.680**	**2.82**	**0.093**
Mannings*Streamflow*Sediment	1	0.061	0.061	0.25	0.616
D50*Streamflow*Sediment	1	0.030	0.030	0.12	0.725
Mannings*D50*Streamflow*Sediment	1	0.000	0.000	0.00	0.976
Error	33564	8095.355	0.241		
Total	33599	10393.022			

S = 0.491113 R-Sq = 22.11% R-Sq(adj) = 22.03%

Overall, Manning's Distribution selection appears to be the most influential approach factor, followed by Streamflow Distribution selection. By comparison, the D_{50} and Sediment Distribution selections are much weaker contributors.

Mannings Sensitivity

The importance of the Mannings distribution demonstrated in the Approach Sensitivity analysis supports the further investigation of Mannings selection, both in terms of distribution selection as well as randomization scheme. The results of this investigation are shown in Table 7 (Maximum Scour); Table 8 (Maximum Deposition); and

Table 9 (Trap Efficiency). Note that because this investigation was not just two-level (since three separate possibilities were considered for the randomization approach) the normal probability plot as shown in the previous section was not an option (this is an inherent restriction in Minitab).

Table 7. Maximum Scour Mannings Sensitivity ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
X-Section (Blocked)	*20*	*3186.65*	*3186.65*	*159.33*	*137.11*	*0.000*
Distribution	1	0.06	0.06	0.06	0.05	0.828
Randomization	**2**	**15.62**	**15.62**	**7.81**	**6.72**	**0.001**
Distribution*Randomization	**2**	**11.78**	**11.78**	**5.89**	**5.07**	**0.006**
Error	12574	14611.79	14611.79	1.16		
Total	12599	17825.89				

S = 1.07799 R-Sq = 18.03% R-Sq(adj) = 17.87%

Table 8. Maximum Deposition Mannings Sensitivity ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
X-Section (Blocked)	*20*	*694.444*	*694.444*	*34.722*	*151.38*	*0.000*
Distribution	**1**	**8.474**	**8.474**	**8.474**	**36.95**	**0.000**
Randomization	2	0.203	0.203	0.101	0.44	0.643
Distribution*Randomization	2	0.864	0.864	0.432	1.88	0.152
Error	12574	2884.102	2884.102	0.229		
Total	12599	3588.087				

S = 0.478926 R-Sq = 19.62% R-Sq(adj) = 19.46%

Table 9. . Trap Efficiency Mannings Sensitivity ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Distribution	**1**	**0.046113**	**0.046113**	**38.10**	**0.000**	
Randomization	2	0.003667	0.001834	1.51	0.221	
Distribution*Randomization	2	0.000630	0.000315	0.26	0.771	
Error	594	0.718966	0.001210			
Total	599	0.769376				

S = 0.0347905 R-Sq = 6.55% R-Sq(adj) = 5.77%

The results show that the selection of Mannings randomization approach is the most important contributor to maximum scour difference; whereas the selection of the Manning's distribution is the most important contributor to maximum deposition difference.

Hence, without knowing whether a particular stream will be primarily in deposition or scour, both the distribution and the randomization approach for Mannings must be carefully considered before conducting the sensitivity analysis.

Realization Number Sensitivity

The results of the realization number sensitivity investigation are shown in the following three figures: Figure 4 (Maximum Scour), Figure 5 (Maximum Deposition), and Figure 6 (Trap Efficiency). These figures plot the 99% Non-Exceedance values normalized by the corresponding value at 10,000 realizations. For Maximum Scour and Deposition, the fluctuation appears to be nearly resolved at 1000 trials. Trap Efficiency remained more or less consistent across all trials, with a maximum fluctuation of only 5%.

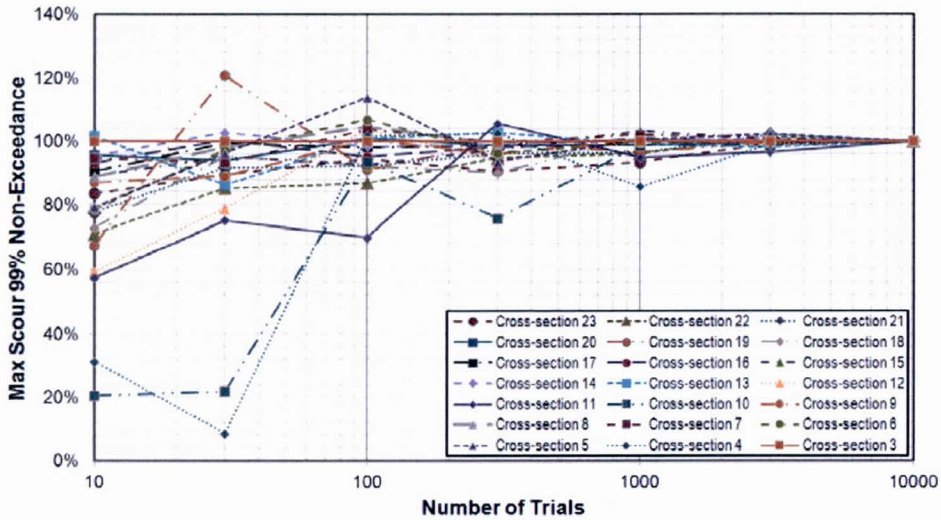

Figure 4. Maximum Scour Realization Number Sensitivity

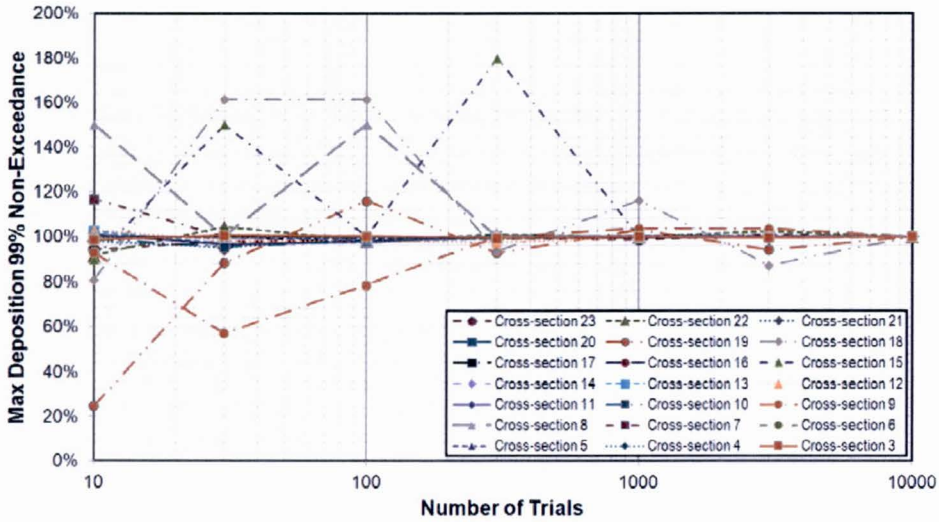

Figure 5. Maximum Deposition Realization Number Sensitivity

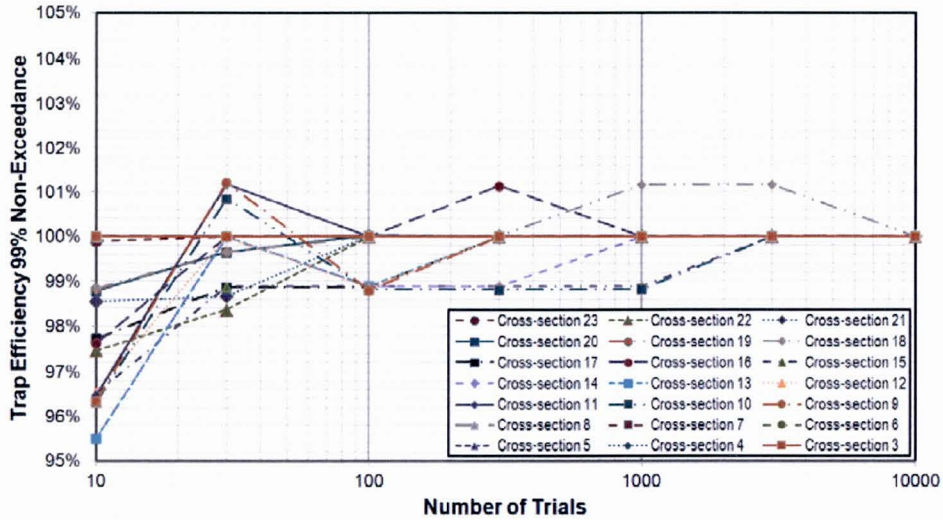

Figure 6. Trap Efficiency Realization Number Sensitivity

CONCLUSIONS

The importance of Mannings *n* selection – both in terms of randomization and distribution approach – cannot be overstated. Consider the bar graph shown in Figure 7, which shows the main effect F values from the ANOVA analyses conducted for the Distribution Approach analysis. The higher the F value the more significant the contribution to the effects. Noting that the bar graph vertical access is logarithmic, the figure shows that the Manning's *n* F values are 10 times as high as the Streamflow values an average, and two magnitudes higher than the D_{50} and Sediment values.

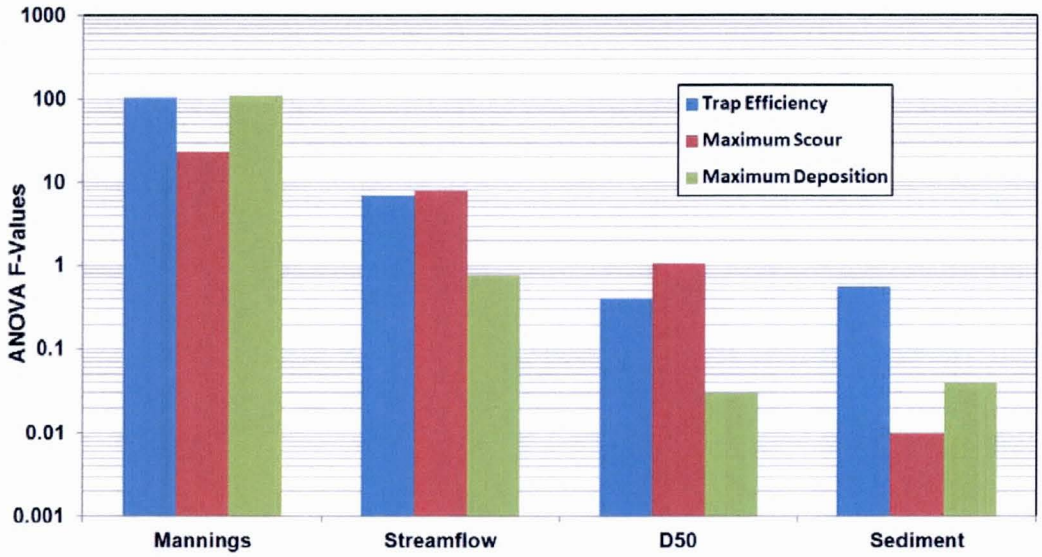

Figure 7. Main Effects F-Values from the Approach Sensitivity ANOVA Analyses

Given the obvious importance of Mannings *n* value implementation, an in-depth investigation of the effects of Manning's *n* distribution selection and randomization approaches was conducted. The results indicated that both aspects of the Monte Carlo simulation were very important.

Finally, graphing 99% exceedance levels for all response variables suggested that a minimum of 1,000 replications should be executed for sensitivity analyses; assuming that the results found here are generalizable to future projects.

Appendix A: Project File

The investigations described in the report used the following input file, modified from the original Centennial Wash evaluation performed by WEST in November, of 2000 (WEST 2000).

```
T1      SCOUR EVALUATION FOR A-B LINE CROSSING CENTENNIAL WASH
T2      PIPELINE SCOUR EVALUATION FOR EPNG, JOB # 273C01, 28JUL00
T3      EQUILIBRIUM SEDIMENT LOAD, 100-YEAR EVENT AFTER DOMINANT DISCHARGE

NC                              0.1     0.3
NV    12     1.0   835.4   0.045   836.4
NV    21   0.025   820.0
NV    32     1.0   838.0   0.045   839.0
X1   3.0      55  6999.8  7563.3
X3    10
GR 845.0  1000.0   844.0  1185.0   840.0  1710.0   838.0  1760.0   837.0  2330.0
GR 838.0  2800.0   836.0  2880.0   835.2  3000.0   836.6  3121.3   835.9  3399.9
GR 835.9  4199.9   835.9  4599.9   835.7  4999.9   836.0  5399.9   835.3  5799.9
GR 835.0  5968.6   835.5  6027.4   827.6  6059.3   828.7  6099.9   834.1  6156.6
GR 831.0  6175.5   834.0  6199.9   834.3  6211.5   834.5  6454.0   833.9  6599.9
GR 834.1  6730.1   832.9  6766.6   835.3  6957.6   835.4  6999.8   834.2  7335.0
GR 832.0  7399.8   830.1  7431.3   829.1  7448.2   824.1  7470.2   826.1  7515.6
GR 838.0  7563.3   838.1  7618.1   836.0  7679.6   836.1  7729.6   836.3  7780.7
GR 835.9  7837.7   835.5  7898.1   836.3  7947.2   836.5  8000.8   837.5  8051.5
GR 837.8  8103.9   837.0  8163.0   835.7  8259.0   834.8  8323.2   836.2  8599.8
GR 837.8  8844.5   842.2  8999.8   841.1  9399.8   843.4  9799.8   843.9  9900.7
HD   3.0     20.   1000.  9900.7
HE   3.0          6999.8  7563.3

NV    12     1.0   841.9   0.045   843.9
NV    32     1.0   839.9   0.045   841.9
X1   4.0      62  9090.4  9497.3   685.0   700.0   720.0
X3    10
GR 852.0  1000.0   844.0  2000.0   842.0  2260.0   840.0  3100.0   840.0  3760.0
GR 844.3  4000.0   843.8  4105.3   840.7  4295.0   840.0  4700.1   838.9  4714.7
GR 839.1  4799.9   838.7  5199.9   838.3  5599.9   837.6  5999.9   838.2  6399.9
GR 839.0  6783.2   840.0  6799.9   840.0  6805.5   839.7  6838.5   839.2  6890.4
GR 839.3  7199.9   838.8  7599.9   838.5  7829.5   839.4  7842.3   839.4  7875.9
GR 834.7  7931.3   836.9  7999.8   837.2  8035.7   837.4  8399.8   836.8  8662.8
GR 828.6  8676.3   829.0  8688.3   834.5    8725   838.4  8749.6   838.8  8758.4
GR 837.9  8787.9   843.2  8793.5   839.0  8851.3   839.1  8911.4   837.0  9021.3
GR 837.9  9068.5   841.9  9090.4   839.3  9104.0   825.8  9139.0   827.3  9163.9
GR 838.2  9219.2   836.6  9266.9   831.9  9271.9   831.9  9288.4   829.6  9308.5
GR 829.9  9315.1   838.3  9325.2   838.8  9379.4   839.7  9429.9   839.9  9497.3
GR 839.5  9537.5   839.7  9585.2   839.6  9639.1   840.5 10399.8   842.6 10799.8
GR 844.5 11199.8   844.8 11248.4
HD   4.0     20.   1000. 11248.4
HE   4.0          9090.4  9497.3

NV    12     1.0   847.0   0.045   849.0
NV    32     1.0   842.8   0.045   844.8
X1   5.0      53  7901.9  8227.7   540.0   540.0   540.0
X3    10
GR 847.8  1000.0   844.0  1320.0   842.0  1970.0   841.5  2680.0   844.0  2780.0
GR 847.0  3000.0   844.7  3258.3   843.1  3293.7   842.7  3799.9   841.8  4199.9
GR 840.8  4519.9   840.0  4533.6   840.1  4599.9   840.6  4999.9   841.2  5399.9
GR 841.3  5799.9   841.3  6199.9   841.2  6205.4   839.7  6215.2   840.6  6227.7
GR 839.5  6246.1   839.0  6599.8   839.0  6999.8   839.0  7399.8   839.3  7670.0
GR 839.2  7709.7   840.5  7764.1   842.9  7889.9   842.2  7895.0   847.0  7901.9
GR 838.1  8037.0   837.6  8060.0   833.2  8073.2   831.8  8101.3   832.6  8165.7
GR 842.8  8227.7   841.6  8282.2   841.3  8381.0   841.2  8433.7   840.5  8669.0
GR 840.5  8693.8   840.6  8728.7   839.8  8843.2   838.5  8864.1   840.9  8890.7
```

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GR 837.6  8907.9   837.8  8923.6   841.7  8999.8   841.7  9003.1   842.4  9399.8
GR 844.3  9799.8   846.4 10199.7   847.7 10461.3
HD   5.0     20.   1000. 10461.3
HE   5.0          7901.9  8227.7

NV    12     1.0   848.3   0.045   851.3
NV    32     1.0   851.3   0.045   853.3
X1   6.0      60  9976.4 10373.7   520.0   540.0   530.0
X3    10
GR 852.0  1000.0   852.0  1650.0   855.0  2150.0   853.0  3310.0   852.0  3490.0
GR 848.0  3510.0   844.0  3530.0   843.0  3640.0   844.0  3760.0   852.0  3800.0
GR 853.1  4000.0   841.8  4169.5   845.0  4399.9   845.6  5199.9   845.2  5599.9
GR 845.0  5999.9   844.4  6399.9   844.4  6799.9   843.8  7199.9   843.2  7599.8
GR 841.9  7999.8   841.3  8248.3   839.2  8291.2   839.0  8399.8   838.7  8799.8
GR 839.1  8900.3   844.1  8937.0   844.1  8977.0   839.3  9011.1   839.1  9023.2
GR 841.7  9044.1   842.0  9199.8   840.4  9700.0   840.7  9754.8   841.6  9806.0
GR 841.2  9853.9   841.0  9902.2   841.8  9951.1   848.3  9976.4   846.1 10009.9
GR 841.2 10023.4   842.6 10035.1   838.8 10103.0   834.0 10168.7   833.8 10188.6
GR 840.0 10205.0   842.5 10227.7   843.8 10234.7   841.3 10254.0   842.0 10268.5
GR 843.7 10271.7   847.1 10316.7   851.3 10373.7   847.5 10455.1   846.7 10507.7
GR 843.4 10519.1   845.8 10538.5   846.1 10799.8   847.9 11199.7   853.5 11486.9
HD   6.0     20.   1000. 11486.9
HE   6.0          9976.4 10373.7

NV    12     1.0   852.4   0.045   854.4
NV    32     1.0   850.2   0.045   852.2
X1   7.0      54  9955.5 10439.7   470.0   500.0   520.0
X3    10
GR 852.0  1000.0   852.0  1650.0   855.0  2150.0   853.0  3310.0   852.0  3490.0
GR 848.0  3510.0   844.0  3530.0   843.0  3640.0   844.0  3760.0   852.0  3800.0
GR 853.1  4000.0   841.8  4169.5   845.0  4399.9   845.6  5199.9   845.2  5599.9
GR 845.0  5999.9   844.4  6399.9   844.4  6799.9   843.8  7199.9   843.2  7599.8
GR 841.9  7999.8   841.3  8248.3   839.2  8291.2   839.0  8399.8   838.7  8799.8
GR 839.1  8900.3   844.1  8937.0   844.1  8977.0   839.3  9011.1   839.1  9023.2
GR 841.7  9044.1   842.0  9199.8   841.5  9599.8   841.9  9929.2   844.4  9930.9
GR 852.4  9955.5   852.0  9977.5   845.0 10046.7   842.3 10095.8   837.9 10178.4
GR 835.0 10196.3   835.3 10208.0   843.8 10244.8   844.3 10295.3   845.0 10360.6
GR 847.1 10424.3   850.2 10439.7   847.5 10455.1   846.7 10507.7   843.4 10519.1
GR 845.8 10538.5   846.1 10799.8   847.9 11199.7   853.5 11486.9
HD   7.0     20.   1000. 11486.9
HE   7.0          9955.5 10439.7

NV    12     1.0   854.8   0.045   856.8
NV    32     1.0   851.6   0.045   853.6
X1   8.0      59  9977.8 10351.8   350.0   430.0   400.0
X3    10
GR 852.0  1000.0   852.0  1650.0   855.0  2150.0   853.0  3310.0   852.0  3490.0
GR 848.0  3510.0   844.0  3530.0   843.0  3640.0   844.0  3760.0   852.0  3800.0
GR 853.1  4000.0   841.8  4169.5   845.0  4399.9   845.6  5199.9   845.2  5599.9
GR 845.0  5999.9   844.4  6399.9   844.4  6799.9   843.8  7199.9   843.2  7599.8
GR 841.9  7999.8   841.3  8248.3   839.2  8291.2   839.0  8399.8   838.7  8799.8
GR 839.1  8900.3   844.1  8937.0   844.1  8977.0   839.3  9011.1   839.1  9023.2
GR 841.7  9044.1   842.0  9199.8   841.5  9599.8   841.9  9932.2   844.5  9936.6
GR 845.0  9936.6   846.1  9938.8   854.6  9962.4   854.8  9977.8   850.0  9991.4
GR 846.1 10040.2   842.8 10100.1   840.5 10151.3   835.6 10201.7   836.2 10222.7
GR 849.9 10265.2   846.4 10274.1   847.4 10333.3   851.6 10351.8   851.5 10358.6
GR 845.9 10385.7   846.2 10411.8   848.0 10458.3   846.7 10507.7   843.4 10519.1
GR 845.8 10538.5   846.1 10799.8   847.9 11199.7   854.0 11486.9
HD   8.0     20.   1000. 11486.9
HE   8.0          9977.8 10351.8

NV    12     1.0   855.7   0.045   857.7
NV    32     1.0   848.0   0.045   850.0
```

```
X1   9.0      53  9348.6  9751.0   460.0   630.0   570.0
X3    10
GR 860.0  1000.0   856.0  1100.0   856.0  1190.0   852.0  1335.0   848.0  1590.0
GR 848.0  1760.0   845.0  2340.0   844.0  3570.0   848.0  3760.0   852.0  3870.0
GR 853.1  4000.0   844.2  4266.5   846.9  4399.9   846.5  4799.9   846.0  5199.9
GR 846.0  5599.9   846.2  5999.9   845.4  6399.9   844.3  6799.9   843.4  7199.9
GR 842.9  7291.0   847.1  7321.4   847.3  7357.1   843.1  7388.1   843.1  7599.8
GR 843.1  7999.8   843.2  8239.2   844.5  8257.2   844.2  8375.0   844.1  8399.8
GR 843.9  8799.8   844.5  9150.0   844.5  9209.7   845.0  9288.7   845.9  9307.9
GR 847.3  9313.5   855.5  9334.6   855.7  9348.6   852.0  9358.1   847.5  9398.2
GR 842.4  9448.7   839.1  9502.0   835.6  9540.0   835.9  9547.4   845.5  9588.0
GR 844.0  9612.1   846.2  9663.1   848.0  9751.0   848.5 10035.0   848.9 10118.6
GR 849.7 10399.8   852.2 10799.8   855.3 11156.5
HD   9.0     20.   1000. 11156.5
HE   9.0          9348.6  9751.0

NV    12     1.0   857.1    0.06   859.1
NV    21   0.025   830.0
NV    32     1.0   847.7   0.065   849.7
X1  10.0      48  8904.9  9364.8   450.0   700.0   600.0
X3    10
GR 856.0  1000.0   848.0  1620.0   846.0  2590.0   848.0  3200.0   848.0  4830.0
GR 843.1  5000.0   846.6  5272.0   853.6  5399.9   844.8  5931.0   845.8  6199.9
GR 847.6  6459.2   847.6  6481.0   844.7  6502.4   845.2  6599.9   844.8  6999.9
GR 844.9  7321.6   846.2  7367.2   846.2  7399.9   846.2  7799.9   846.0  8199.9
GR 846.4  8546.0   846.5  8670.0   850.6  8730.0   850.4  8741.2   845.3  8761.8
GR 844.8  8802.3   846.0  8850.8   856.6  8869.1   857.1  8904.9   851.9  8916.1
GR 852.7  8929.3   845.4  8979.9   840.7  9030.3   835.8  9072.4   835.1  9089.1
GR 835.8  9113.1   843.0  9127.5   844.8  9143.1   846.8  9193.1   841.1  9202.8
GR 843.4  9294.2   847.0  9298.1   847.7  9364.8   847.5  9399.8   847.8  9799.8
GR 849.2 10199.8   849.2 10201.3   855.4 10521.8
HD  10.0     20.   1000. 10521.8
HE  10.0          8904.9  9364.8

NV    12     1.0   857.4    0.06   859.4
NV    32     1.0   854.0   0.065   856.0
X1  11.0      44  8887.8  9227.4   530.0   650.0   525.0
X3    10
GR 856.0  1000.0   848.0  1620.0   846.0  2590.0   848.0  3200.0   848.0  4830.0
GR 843.1  5000.0   846.6  5272.0   853.6  5399.9   844.8  5931.0   845.8  6199.9
GR 847.6  6459.2   847.6  6481.0   844.7  6502.4   845.2  6599.9   844.8  6999.9
GR 844.9  7321.6   846.2  7367.2   846.2  7399.9   846.2  7799.9   846.0  8199.9
GR 846.4  8546.0   846.5  8670.0   850.6  8730.0   850.4  8741.2   847.1  8750.0
GR 847.5  8799.3   847.8  8839.5   857.0  8868.9   857.4  8887.8   853.3  8910.5
GR 848.3  8963.1   843.6  9015.2   839.9  9054.9   836.6  9081.3   835.8  9126.9
GR 846.9  9167.3   848.7  9205.0   854.0  9227.4   848.4  9249.8   847.5  9399.8
GR 847.8  9799.8   849.2 10199.8   849.2 10201.3   855.4  10522.
HD  11.0     20.   1000. 10522.0
HE  11.0          8887.8  9227.4

NV    12     1.0   856.0    0.06   858.0
NV    32     1.0   854.4   0.065   856.4
X1  12.0      41  8900.6  9168.8   500.0   100.0   460.0
X3    10
GR   860    1000     848    1620     846    2590     848    3200     848    4830
GR 843.1    5000   846.6    5272   853.6  5399.9   844.8    5931   845.8  6199.9
GR 847.6  6459.2   847.6    6481   844.7  6502.4   845.2  6599.9   844.8  6999.9
GR 844.9  7321.6   846.2  7367.2   846.2  7399.9   846.2  7799.9   846.2  8199.9
GR 847.2    8546   847.6  8599.8   848.4    8750   848.9  8804.6   850.7  8859.1
GR  856.  8888.7   856.0  8900.6   850.6  8922.4   845.4  8969.3     839  9010.6
GR 837.7  9092.4   849.5  9124.7   854.4  9168.8   854.4  9183.2   849.3  9193.6
GR 849.3  9254.9   849.0  9399.8   849.0  9799.8   849.2 10199.8   849.2 10201.3
GR  860. 10522.0
```

```
HD  12.0     20.   1000. 10522.0
HE  12.0          8900.6  9168.8


  In the midle of the bridge
NC                            .3      .5
NV    12     1.0   855.0    0.06   857.0
NV    32     1.0   855.0   0.065   857.0
X1  13.0      41  8900.6  9168.8   130.0    80.0   130.0
X3    10
GR   860    1000     848    1620     846    2590     848    3200     848    4830
GR 843.1    5000   846.6    5272   853.6  5399.9   844.8    5931   845.8  6199.9
GR 847.6  6459.2   847.6    6481   844.7  6502.4   845.2  6599.9   844.8  6999.9
GR 844.9  7321.6   846.2  7367.2   846.2  7399.9   846.2  7799.9   846.2  8199.9
GR 847.2    8546   847.6  8599.8   848.4    8750   848.9  8804.6   850.7  8859.1
GR  856.  8888.7   856.0  8900.6   850.6  8922.4   845.4  8969.3     839  9010.6
GR 837.7  9092.4   849.5  9124.7   855.0  9168.8   854.4  9183.2   849.3  9193.6
GR 849.3  9254.9   849.0  9399.8   849.0  9799.8   849.2 10199.8   849.2 10201.3
GR  860. 10522.0
HD  13.0     20.   1000. 10522.0
HE  13.0          8900.6  9168.8

NC                            0.4     0.6
NV    14  -0.035   10000   0.040   20000   0.355   30000   0.010   40000
NV    24  -0.035   10000   0.045   20000   0.355   30000   0.010   40000
X1  14.0      49  5975.4  6160.0   730.0    30.0   200.0
X3    10
XL                                 6160.0
GR 860.4  1000.0   859.5  1399.9   859.2  1799.9   856.9  2311.4   858.2  2329.9
GR 857.3  2345.4   856.2  2599.9   854.0  2999.9   853.6  3399.9   853.0  3595.7
GR 854.3  3617.9   852.3  3646.4   852.5  3799.9   851.6  4199.9   850.4  4599.8
GR 851.1  4999.8   851.1  5399.8   850.8  5600.0   851.0  5650.3   851.2  5700.5
GR 851.3  5752.1   851.1  5802.1   851.1  5851.2   851.5  5903.4   851.1  5972.8
GR 852.0  5975.4   851.6  6032.2   851.1  6081.0   838.6  6089.9   845.6  6101.0
GR 850.3  6113.8   850.4  6138.3   858.5  6160.0   858.4  6170.2   856.7  6175.1
GR 857.1  6187.0   857.0  6191.9   855.5  6199.9   855.2  6211.9   849.5  6279.0
GR 850.1  6309.2   849.9  6365.5   850.2  6421.4   849.8  6476.4   849.6  6532.0
GR 849.9  6599.8   852.0  6720.0   856.0  6800.0   859.0    7000
HD  14.0     20.   1000.  7000.0
HE  14.0          5975.4  6160.0

NC                            0.1     0.3
NV    12     1.0   851.5    0.04   853.5
NV    21   0.030   840.0
NV    32     1.0   857.9   0.045   858.9
X1  15.0      58  5898.5  6184.7   810.0    40.0   500.0
X3    10
GR 860.4  1000.0   859.5  1399.9   859.2  1799.9   856.9  2311.4   858.2  2329.9
GR 857.3  2345.4   856.2  2599.9   854.0  2999.9   853.6  3399.9   853.0  3595.7
GR 854.3  3617.9   852.3  3646.4   852.5  3799.9   851.6  4199.9   850.4  4599.8
GR 851.1  4999.8   851.1  5399.8   848.4  5580.0   848.3  5647.6   847.0  5672.2
GR 851.3  5675.3   850.3  5690.4   850.0  5751.5   844.0  5759.8   843.7  5772.3
GR 849.7  5780.9   849.8  5821.0   849.9  5868.2   851.5  5898.5   850.0  5963.6
GR 844.7  5969.6   845.4  5979.9   850.2  5990.2   850.0  6062.4   841.8  6072.6
GR 843.4  6083.8   848.3  6096.7   853.2  6151.8   857.7  6168.8   857.9  6184.7
GR 856.2  6190.3   856.7  6202.2   856.7  6206.9   855.0  6223.7   847.5  6270.0
GR 847.7  6284.0   849.9  6332.4   849.4  6376.0   849.6  6412.4   847.3  6421.2
GR 849.1  6429.7   848.6  6475.7   848.7  6528.4   848.7  6579.3   848.9  6631.0
GR 852.0  6720.0   856.0  6800.0   859.0    7000
HD  15.0     20.   1000.  7000.0
HE  15.0          5898.5  6184.7

NV    12     1.0   852.1    0.04   854.1
```

```
NV    32     1.0   858.6   0.045   859.6
X1  16.0      49  6015.5  6161.2   490.0   300.0   540.0
X3    10
GR 860.4  1000.0   859.5  1399.9   859.2  1799.9   856.9  2311.4   858.2  2329.9
GR 857.3  2345.4   856.2  2599.9   854.0  2999.9   853.6  3399.9   853.0  3595.7
GR 854.3  3617.9   852.3  3646.4   852.5  3799.9   851.6  4199.9   850.4  4599.8
GR 851.1  4999.8   851.1  5399.8   850.9  5640.0   851.0  5690.3   851.2  5740.5
GR 851.3  5792.1   851.1  5842.1   851.1  5891.2   851.5  5943.4   851.1  6012.9
GR 852.1  6015.5   851.6  6033.4   851.1  6082.2   844.6  6091.1   845.7  6102.2
GR 850.3  6115.0   850.4  6139.5   858.6  6161.2   858.5  6171.4   856.7  6176.3
GR 857.1  6188.2   857.1  6193.1   855.5  6201.1   855.2  6204.9   849.6  6272.0
GR 850.1  6302.2   850.0  6358.5   850.2  6414.5   849.8  6469.5   849.6  6525.1
GR 849.9  6599.8   852.0  6720.0   856.0  6800.0   859.0    7000
HD  16.0     20.   1000.  7000.0
HE  16.0          6015.5  6161.2

NV    12     1.0   852.9    0.04   854.5
NV    32     1.0   859.3   0.045   860.3
X1  17.0      51  5971.5  6177.7   310.0   440.0   390.0
X3    10
GR 860.4  1000.0   859.5  1399.9   859.2  1799.9   856.9  2311.4   858.2  2329.9
GR 857.3  2345.4   856.2  2599.9   854.0  2999.9   853.6  3399.9   853.0  3595.7
GR 854.3  3617.9   852.3  3646.4   852.5  3799.9   851.6  4199.9   850.4  4599.8
GR 851.1  4999.8   851.1  5399.8   851.6  5670.0   852.0  5721.5   851.8  5772.7
GR 851.5  5825.2   851.8  5880.9   852.3  5934.0   852.9  5971.5   852.9  5992.3
GR 852.9  6005.5   848.8  6021.7   848.0  6039.6   852.9  6044.1   852.7  6063.7
GR 850.1  6074.6   851.7  6146.2   859.2  6166.3   859.3  6177.7   857.3  6184.7
GR 857.7  6194.7   857.7  6199.5   856.3  6215.0   853.9  6223.3   847.6  6305.2
GR 847.9  6327.0   851.6  6347.8   851.2  6408.5   851.5  6459.8   851.5  6508.3
GR 850.0  6516.1   851.5  6524.9   851.7  6574.0   851.7  6628.3   856.0  6800.0
GR 859.0    7000
HD  17.0     20.   1000.  7000.0
HE  17.0          5971.5  6177.7

NV    12     1.0   852.6    0.04   853.8
NV    32     1.0   857.7   0.045   859.7
X1  18.0      60  5710.9  5907.8   440.0   540.0   540.0
X3    10
GR 860.4  1000.0   859.5  1399.9   859.2  1799.9   856.9  2311.4   858.2  2329.9
GR 857.3  2345.4   856.2  2599.9   854.0  2999.9   853.6  3399.9   853.0  3595.7
GR 854.3  3617.9   852.3  3646.4   852.5  3799.9   851.9  4199.9   851.6  4599.8
GR 851.8  4999.8   851.9  5399.8   852.2  5500.0   852.7  5549.7   852.7  5603.6
GR 852.7  5657.4   852.6  5710.9   852.7  5766.1   849.7  5784.4   852.6  5805.6
GR 853.6  5830.5   853.5  5835.3   851.2  5836.2   854.0  5847.4   856.2  5849.8
GR 853.7  5861.7   856.8  5862.7   856.4  5865.9   856.7  5869.0   855.1  5876.5
GR 856.9  5878.1   857.7  5907.8   854.2  5909.4   853.5  5914.3   849.9  5914.5
GR 852.7  5922.5   855.5  5965.6   852.8  5987.2   852.8  6040.4   854.1  6085.5
GR 852.8  6123.1   861.3  6142.3   861.6  6154.9   860.2  6159.3   860.7  6174.0
GR 860.7  6178.9   859.0  6185.5   858.8  6195.5   851.5  6220.1   848.1  6245.7
GR 848.3  6261.9   853.6  6276.3   854.0  6760.0   856.0  6800.0   860.5    7000
HD  18.0     20.   1000.  7000.0
HE  18.0          5710.9  5907.8

NV    12     1.0   859.2    0.04   861.2
NV    32     1.0   855.5   0.045   857.1
X1  19.0      42  5256.2  5353.3   430.0   550.0   540.0
X3    10
GR 863.5  1000.0   862.7  1144.3   859.5  1167.5   858.8  1799.9   859.0  1952.9
GR 855.1  1967.6   854.2  2199.9   853.9  2599.9   853.4  2999.9   853.2  3399.9
GR 853.6  3799.9   852.7  4199.8   852.8  4599.8   853.1  4850.0   853.1  4899.1
GR 853.0  4951.3   853.0  5004.7   853.0  5057.2   852.5  5110.2   853.0  5162.0
GR 854.8  5218.6   858.3  5236.3   858.9  5237.9   859.2  5256.2   856.0  5277.1
GR 854.5  5281.6   851.1  5291.7   851.5  5306.7   855.5  5353.3   855.8  5403.6
```

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GR 856.0  5452.2   856.2  5507.6   856.7  5560.3   857.2  5613.7   857.2  5647.8
GR 853.8  5662.8   853.5  5695.0   864.1  5718.5   864.0  5729.8   862.5  5734.5
GR 863.8  5748.2   863.7  5752.9
HD  19.0     20.   1000.  5752.9
HE  19.0          5256.2  5314.1

NV    12     1.0   861.2    0.04   863.2
NV    32     1.0   856.7   0.045   858.7
X1  20.0      44  5270.0  5365.3   160.0   430.0   400.0
X3    10
GR 863.5  1000.0   862.7  1144.3   859.5  1167.5   858.8  1799.9   859.0  1952.9
GR 855.1  1967.6   854.2  2199.9   853.9  2599.9   853.4  2999.9   853.2  3399.9
GR 853.6  3799.9   853.7  4199.8   853.6  4835.0   853.5  4888.9   853.5  4938.5
GR 853.3  4991.0   853.4  5044.8   853.6  5098.8   853.1  5151.6   853.3  5204.7
GR 854.8  5249.2   860.8  5267.5   861.2  5270.0   861.0  5281.8   855.6  5295.3
GR 855.0  5316.6   851.7  5325.8   851.4  5335.3   855.1  5340.8   855.6  5349.3
GR 856.7  5365.3   857.1  5419.7   859.1  5475.0   857.6  5531.2   857.0  5586.8
GR 858.0  5641.1   858.2  5694.8   857.7  5749.8   858.7  5803.2   859.7  5868.6
GR 856.1  5881.4   856.2  5922.3   859.4  5933.0   863.5  5944.5
HD  20.0     20.   1000.  5944.5
HE  20.0          5270.0  5365.3

NV    12     1.0   861.6    0.04   863.6
NV    32     1.0   857.2   0.045   858.8
X1  21.0      40  5238.6  5420.6   200.0   520.0   480.0
X3    10
GR 863.5  1000.0   862.7  1144.3   859.5  1167.5   858.8  1799.9   859.0  1952.9
GR 855.1  1967.6   854.2  2199.9   853.9  2599.9   853.4  2999.9   853.2  3399.9
GR 853.6  3799.9   853.8  4199.8   854.7  4820.0   854.7  4884.8   854.5  4935.7
GR 854.5  4988.6   854.7  5041.0   854.8  5095.2   854.7  5147.6   855.3  5202.4
GR 856.5  5223.1   861.6  5238.6   860.9  5243.9   861.5  5260.0   860.7  5260.1
GR 856.4  5272.6   855.9  5297.6   854.1  5304.5   853.2  5316.7   855.7  5323.7
GR 856.9  5375.0   857.2  5420.6   858.6  5472.4   859.3  5525.5   860.3  5577.2
GR 860.0  5630.4   861.3  5681.8   861.7  5734.7   862.0  5787.9   863.6  5840.2
HD  21.0     20.   1000.  5840.2
HE  21.0          5238.6  5420.6

NV    12     1.0   862.6    0.04   864.6
NV    32     1.0   857.8   0.045   859.4
X1  22.0      41  5113.1  5209.8   280.0   790.0   660.0
X3    10
XL                                 5850.
GR 864.8  1000.0   863.8  1024.3   859.6  1044.9   860.0  1408.3   856.0  1446.8
GR 855.0  1799.9   854.9  2199.9   854.8  2599.9   854.6  2999.9   854.5  3399.9
GR 854.6  3799.9   855.4  4700.0   855.4  4752.9   855.4  4806.6   855.5  4860.7
GR 855.5  4915.0   855.6  4969.4   855.8  5024.9   856.3  5091.2   862.2  5109.5
GR 862.6  5113.1   862.3  5121.8   857.8  5140.5   857.0  5183.8   854.2  5190.7
GR 854.5  5201.9   857.8  5209.8   857.7  5264.4   858.1  5334.0   857.9  5387.0
GR 858.1  5438.3   858.2  5491.6   858.3  5538.8   858.9  5600.0   858.8  5652.6
GR 861.1  5799.8   861.1  6025.4   861.2  6035.3   861.3  6079.2   867.6  6131.8
GR 867.7  6141.3
HD  22.0     20.   1000.  6141.3
HE  22.0          5113.1  5209.8

NV    12     1.0   862.9    0.04   864.9
NV    32     1.0   859.6   0.045   861.2
X1  23.0      46  5065.2  5237.2   280.0   540.0   480.0
X3    10
GR 868.7  1000.0   862.5  1379.8   859.9  1391.5   860.1  1583.0   856.3  1606.9
GR 857.0  1799.9   856.6  1942.2   857.8  1987.7   858.0  2114.1   855.9  2141.1
GR 856.4  2199.9   856.2  2599.9   856.5  2999.9   856.4  3399.9   856.5  3799.9
GR 855.8  4199.8   856.3  4625.0   856.3  4677.9   856.3  4733.2   856.5  4786.5
GR 856.6  4842.1   856.5  4897.2   856.6  4951.7   856.6  5008.6   857.5  5049.5
```

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GR 862.5  5062.9   862.9  5065.2   862.1  5076.2   858.1  5087.5   857.9  5092.1
GR 855.3  5103.6   856.3  5125.2   857.9  5130.9   859.2  5184.0   859.6  5237.2
GR 859.1  5291.1   859.4  5342.1   860.2  5396.8   862.2  5448.1   862.3  5530.1
GR 862.4  5596.6   862.5  5628.8   862.5  5799.8   862.6  6123.4   864.7  6199.8
GR 870.1  6452.9
HD  23.0     20.   1000.  6452.9
HE  23.0          5065.2  5237.2
EJ

T4  SEDIMENT DATA FOR THE CENTENNIAL WASH
T5  BED GRADATION FROM THE FIELD
T6  EQUILIBRIUM SEDIMENT INFLOW
T7  YANG'S (1973) STREAM POWER FUNCTION USED FOR SEDIMENT
T8  TRANSPORT
I1            50
I4             4       1      10
LQ     Q   1000.   5000.  13400.  30000.  67600.
LT SLOAD  11000.  91000. 300000. 700000. 1500000
LF   VFS   0.196   0.208   0.277   0.250   0.254
LF    FS   0.209   0.221   0.271   0.258   0.260
LF    MS   0.230   0.200   0.175   0.190   0.189
LF    CS   0.172   0.164   0.130   0.136   0.133
LF   VCS   0.182   0.203   0.146   0.166   0.164
LF   VFG   0.003   0.001   0.000   0.000   0.000
LF    FG   0.004   0.001   0.000   0.000   0.000
LF    MG   0.003   0.001   0.000   0.000   0.000
LF    CG   0.000   0.001   0.001   0.000   0.000
LF   VCG   0.000   0.000   0.000   0.000   0.000
     TEST PIT #3 (6-8), THALWEG ~220 FEET DOWNSTREAM OF THE SPRR BRIDGE
PF          12.0     1.0    64.0    37.5    100.    25.0    97.0    19.0    94.0
PFC 12.5    88.0     9.5    82.0     6.3    75.0    4.75    67.0    2.36    53.0
PFC  2.0    49.0    1.18    36.0    0.60    23.0   0.425    16.0     0.3    11.0
PFC 0.15     6.0   0.075    5.21
     TEST PIT #4 (0-3), THALWEG ~1980 FEET UPSTREAM OF THE SPRR BRIDGE
PF          17.0     1.0    64.0    37.5    100.    25.0    99.0    19.0    99.0
PFC 12.5    98.0     9.5    97.0     6.3    94.0    4.75    91.0    2.36    80.0
PFC  2.0    77.0    1.18    68.0    0.60    58.0   0.425    50.0     0.3    41.0
PFC 0.15    21.0   0.075   13.97
     TEST PIT #5 (6-10), THALWEG ~3300 FEET UPSTREAM OF THE SPRR BRIDGE
PF          20.0     1.0    64.0    37.5    100.    25.0    98.0    19.0    96.0
PFC 12.5    87.0     9.5    82.0     6.3    74.0    4.75    68.0    2.36    54.0
PFC  2.0    50.0    1.18    37.0    0.60    25.0   0.425    19.0     0.3    15.0
PFC 0.15    10.0   0.075    8.22
     TEST PIT #6 (0-1.5), THALWEG ~46200 FEET UPSTREAM OF THE SPRR BRIDGE
PF          23.0     1.0    64.0    37.5    100.    25.0   100.0    19.0   100.0
PFC 12.5    99.0     9.5    98.0     6.3    93.0    4.75    89.0    2.36    71.0
PFC  2.0    66.0    1.18    50.0    0.60    35.0   0.425    27.0     0.3    19.0
PFC 0.15    12.0   0.075   10.33

$HYD
$MXMN  0       0       3       0
*   BB
Q  1000.
R 835.20
T     65
X           .1     10.
*   BB
Q 10000.
R 835.20
X          .01  .08333
*   BB
Q 20000.
R 836.78
```

```
X          .01  .16666
*   BB
Q 27500.
R 837.46
X          .01     .25
*   BB
Q 45000.
R 838.49
X          .01     .25
*   BB
Q 60000.
R 839.23
X          .01  .16666
*   BB
Q 67600.
R 839.59
X          .01  .16666
*   BB
Q 60000.
R 839.23
X          .01    .125
*   BB
Q 50000.
R 838.74
X          .01    .125
*   BB
Q 40000.
R 838.24
X          .01  .20833
*   BB
Q 30000.
R 837.69
X          .01  .20833
*   BB
Q 20000.
R 836.78
X          .01  .33333
*   BB
Q 12000.
R 835.52
X          .01      .5
*   BB
Q  5000.
R 832.53
X          .01  .91666
*   BB
Q  2500.
R 830.31
X          .01  1.8333
$$END

  Q  1000.   2500.   5000.  10000.  20000.  30000.  40000.  50000.  60000.  6700
  R 827.68  829.18  830.85  833.40  835.88  836.57  837.11  837.60  838.06  838.
  T    65.     65.     65.     65.     65.     65.     65.     65.     65.     6
  W     1.      1.      1.      1.      1.      1.      1.      1.      1.    1.
```

Appendix B: Property Distribution Research

Overview

Multiple approaches are available to conduct uncertainty analyses, including Bayesian statistics, FAST, Latin hypercube, error propagation, and others. However, for complex systems, such as sediment transport modeling, almost all uncertainty analyses rely on Monte Carlo simulation in lieu of direct computation. Indeed, Melching et al. (1987) argue that Monte Carlo simulation may be the best approach for highly non-linear and complex systems uncertainty analysis.

Despite its prevalence in the industry, it is not always recognized that accurate Monte Carlo simulations are strongly dependent upon making the correct assumptions of the input statistical distributions (Melching et al. 1987). However, when these are not well known there is evidence that simple distributions, such as uniform or triangular distributions, are sufficient provided that their bounds are well known (Haan et al. 1998). For sediment transport studies in particular, Schmelter, Hooten, & Stevens (2011) found that the assumption of a uniform distribution was the most robust assumption when the actual input distribution was unknown.

This sub-section briefly describes the literature search, investigation, and recommended parameter distributions to be used for the uncertainty modeling simulations.

Compiled Research

For the four input parameter distributions considered here – Manning's *n*, sediment size D_{50}, peak flow, and sediment inflow – the literature shows a large range of assumptions. Table 10 below tabulates the results.

Table 10. Published Sediment Transport Input Distribution Research

Distribution	Manning's n	D50	Streamflow	Sediment Influx
Uniform	Osidele et al. (2003) Pinto et al. (2006) Griensven et al. (2006) Wohl (1998) Ruark et al. (2011) Hantush and Kalin (2005)	Osidele et al. (2003) Pinto et al. (2006) Hantush and Kalin (2005)		
Normal	Tattari and Barlund (2000) Maurer et al. (1998)	Yanmaz (2003)		Carling et al. (1993) Kuhnle (1996)
Triangular	Muñoz-Carpena et al. (2007)	Muñoz-Carpena et al. (2007)		
Lognormal	Hall et al. (2009) Byrd and Melching (2005) United States Army Corps of Engineers (1986)	Maurer et al. (1998)	Yanmaz (2003) Byrd and Melching (2005)	
Gamma				Turowski (2010) Kuhnle and Willis (1998) Willis and Bolton (1979)
Others			Pinto et al. (2006) – quadratic United States Army Corps of Engineers (1996) – non-central t-distribution	Gomez et al. (1990) - Hamamori

[1] Yanmaz (2003) also included uniform and triangular distributions but were presented for comparative purposes only and were not specifically recommended.

RESEARCH DETAILS

Manning's n

The literature search found that the most common assumption for Manning's *n* uncertainty distribution is uniform or lognormal. Interestingly, of the four parameters investigated herein, the Manning's *n* parameter is the only one whose distribution has been researched directly. As part of the United States Army Corps of Engineers [USACE] (1986) report on the accuracy of computed water surface profiles, the USACE performed an experiment to determine that uncertainties associated with engineer selection of a representative Manning's *n*. Their results indicated that a lognormal distribution fit the mean estimates best with

$$s_n = 0.582 + 0.1 \ln n_0 \tag{1}$$

where s_n is the standard deviation of the natural log estimate and n_0 is the original estimated Manning's *n* value.

Because the USACE has directly researched this area with the specific intent of applying it to Monte Carlo simulations, their method is what is recommended to be used here. Moreover, it has the additional advantage that it can be generated automatically given any particular Manning's *n* value with the need to consult site specific material. The implemented procedure for each simulation would be as follows:

1. Generate a random probability p ($0 < p < 1$);
2. For each Manning's n value (n_0) in the model:
    a. Evaluate s_n given n_0 using Equation (1);
    b. Generate a randomized Manning's *n* (denoted here as $\underline{n_p}$) using the inverse normal distribution function.

In Excel, the inverse normal distribution function is given by $x_p = \text{NORMINV}(p, \bar{x}, s)$ where x_p is the randomized variable, $\bar{x}$ the mean, and s the standard deviation of the distribution respectively. Hence, the direct calculation of n_p is given p and s_n is

$$\ln n_p = \text{NORMINV}(p, \ln n_0, s_n) \tag{2}$$

Note that since the probability p will be generated only once per run, all Manning's *n* numbers will be adjusted the same direction (i.e., all up or all down). This will reflect the tendency to overestimate or underestimate the *n* values over the entire reach and is in strict accordance with the USACE (1986) procedure.

D_{50}

Almost all identified research on sediment D_{50} uncertainty (and representative diameters in general) was found to be specific to overland sediment yield studies (e.g., RUSLE, MUSLE, etc.) Of these six studies, three sources reported utilizing a uniform distribution for D_{50} input and one source each reported using a triangular, normal, and lognormal distribution. This is somewhat surprising, as the

physical limitation on D_{50} – that it be always greater than zero – would seem to encourage the use of the lognormal distribution, as it and the triangular distribution are the only two of the four that are intrinsically bounded by zero (Pinto et al. 2006).

That said, the results of the literature search are clear in its support of the uniform distribution as the best method to represent the D_{50} uncertainty. In this regard, the Pinto procedure (Pinto et al. 2006) seems well suited for the simulation effort. This procedure specifies the lower bound value for D_{50} as a (mm) and the upper bound as b (mm) where

$$a = D_{50}\left(1 - c\sqrt{3}\right) \tag{3}$$

$$b = D_{50}\left(1 + c\sqrt{3}\right) \tag{4}$$

and the coefficient c (dimensionless) is given by:

$$c = \begin{cases} 0.4, \; D_{50} \le 0.6 \text{ mm} \\ 0.2, \; D_{50} > 0.6 \text{ mm} \end{cases} \tag{5}$$

Pinto et al. (2006) explain that the variable range of c was introduced in order to account for the large spatial variability of the property, although they do not go into detail.

The implemented procedure for each simulation would be as follows:

1. Generate a random probability p ($0 < p < 1$);
2. For each D_{50} value in the model:
    a. Determine a and b per Equations (3) and (4).
    b. Generate a randomized D_{50} value (denoted here as D_{50p}) using the following function:

$$D_{50p} = a + (b - a)\,p \tag{6}$$

Streamflow

Few literature sources were found that directly addressed the inherent uncertainties of streamflow estimates. Of the four identified, two recommended using the lognormal distribution. The other two suggested statistical distributions of greater complexity probably not warranted by the state of knowledge at this point. Hence, the lognormal distribution is the one recommended here.

Byrd & Melching (2005) recommends a procedure for using the lognormal distribution that would work well for the simulation. This method utilizes the United States Geological Survey (USGS) database for Arizona (Mason Jr. et al. 1999) to obtain the *Average Standard Error of Prediction in Percent* ε_q in the watershed area and then assumes the standard deviation (denoted here s_q) equals this value times the mean streamflow q_0. That is:

$$s_q = \varepsilon_q q_0 \tag{7}$$

(For example, the Hassayampa River and Gila River locations considered for this project, the corresponding USGS region is 12 and the $\varepsilon_q = 39\%$).

The implemented procedure for each simulation would be as follows:

1. Generate a random probability p ($0 < p < 1$);

2. For each flow q_0 in the model:
    a. Determine μ_q and σ_q corresponding to the transformed mean and standard deviation respectively, per Equations (8) and (9) below. These values will insure distribution consistency with q_0 and s_q.
    b. Generate the randomized peak flow q_p using Equation (10).

$$\mu_q = \ln\left(q_0 / \sqrt{1+\varepsilon_q^2}\right) \tag{8}$$

$$\sigma_q = \sqrt{\ln\left(1+\varepsilon_q^2\right)} \tag{9}$$

$$\ln q_p = \mathrm{NORMINV}(p, \mu_q, \sigma_q) \tag{10}$$

Note that the Excel notation for the inverse normal distribution function has been adopted in Equation (10).

Sediment Inflow

Uncertainty distribution investigations for sediment inflows are fairly rare, undoubtedly due in large part to the difficulties in obtaining sediment inflow data of sufficient size and quality (Turowski 2010). When available, the data tends to show extreme variability, as is evident from the high coefficients of variation (c_v) reported in the literature: 0.8 (Kuhnle and Willis 1998 [sand data]), 1.2 (Turowski 2010), 1.4 (Kuhnle and Willis 1998 [bedload data]), and 1.6 (Willis and Bolton 1979). Thus, with an overall average c_v of about 1.2, the standard deviation of the data is higher than its mean.

In order to meet the challenge of modeling such a strongly deviating dataset, a variety of statistical distributions have been considered in the research, including the Hamamori, Birnbaum-Sanders, normal, exponential, gamma, Carey-Hubbell, and Poisson distributions (Carling et al. 1993; Kuhnle and Willis 1998; Kuhnle 1996; Turowski 2010). Of these, the normal and gamma were the two most often utilized of the common distributions.

Unfortunately, while modeling by a normal distribution is arguably more mathematically convenient than utilizing the gamma distribution, it is not physically realistic since the normal distribution allows negative values for sediment transport estimates at low probabilities. At a minimum the normal distribution would need to be truncated at zero. While this has been done successfully in other studies (e.g. Schmelter et al. 2011) the high c_v values, coupled with the location of the zero transport line typically within two standard deviations from the mean, would require that a large portion of the normal distribution be truncated at zero, which is not realistic (Kuhnle and Willis 1998).

Luckily, the gamma distribution may be an acceptable alternative. It is physically consistent (allowing only positive values), smooth, continuous, and readily accessible from Excel. Three separate studies (Kuhnle and Willis 1998; Turowski 2010; Willis and Bolton 1979) specifically note its applicability and recommend it for field applications.

The implemented procedure for each simulation would be as follows:

1. Generate a random probability p ($0 < p < 1$);
2. Assuming a constant c_v of 1.2 (as noted above), calculate the α and β shape factors per Equations (11) and (12) shown below;
3. For each sediment inflow g_0 in the model, generate the randomized sediment inflow g_p per Equation (13).

$$\alpha = 1 / c_v^2 \tag{11}$$

$$\beta = g_0 c_v^2 \tag{12}$$

$$g_p = \text{GAMMAINV}(p, \alpha, \beta) \tag{13}$$

Note that the Excel notation for the inverse gamma distribution function has been adopted in Equation (13).

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