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Hydrologic and Hydraulic Contributions to Risk and Uncertainty Propagation Studies

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Introduction

- Hydrologic and Hydraulic (H&H) Modeling determines flood levels where human and financial costs occur during events
- Uncertain H&H modeling parameters must be examined to determine risk for the flood reduction study
- Examples: flow rates, gauge record lengths, drainage areas, Manning's "n" values, coefficients of contraction and expansion and pier debris at bridges
- The final results of this analysis will describe the likelihood that an alternative will produce a degree of economic benefit and its probability of exceedance

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Terminology

- Parameter – A quantity in a function that determines the specific form of the relationship of known input and unknown output. Example Manning's "n"
- Parameter uncertainty – Lack of complete knowledge or accuracy of the value of a parameter.
- Sensitivity Analysis – Computation of the effect on the output of changes in input values or assumptions.
- Function uncertainty – Lack of complete knowledge or accuracy of the form of a hydrologic or hydraulic function used in an application such as a flood damage reduction study.

EM-1110-2-1619

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Hydrological and Hydraulic Contributions to Risk and Uncertainty Studies

- ## Hydrologic Uncertainty

Uncertainty with the Discharge – Probability Curve

- ## Hydraulic Uncertainty

Uncertainty with the Stage – Discharge Function

- ## Interior Flooding Uncertainty

Storm Runoff from the watershed that drains to the interior of a levee must be passed through or over the levee (EM-1110-2-1619). Performance of facilities like gravity outlets, pump stations, pump discharge outlets, collection facilities, storm sewers, and detention storage/flooding involves uncertainty

Hydrologic Uncertainty

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- Flood damage reduction projects such as reservoirs, detention storage, diversions, levees, and channels affect the discharge –probability curve
- Therefore, an **uncertainty propagation** study must be performed

2 Methods to perform hydrologic uncertainty propagation study

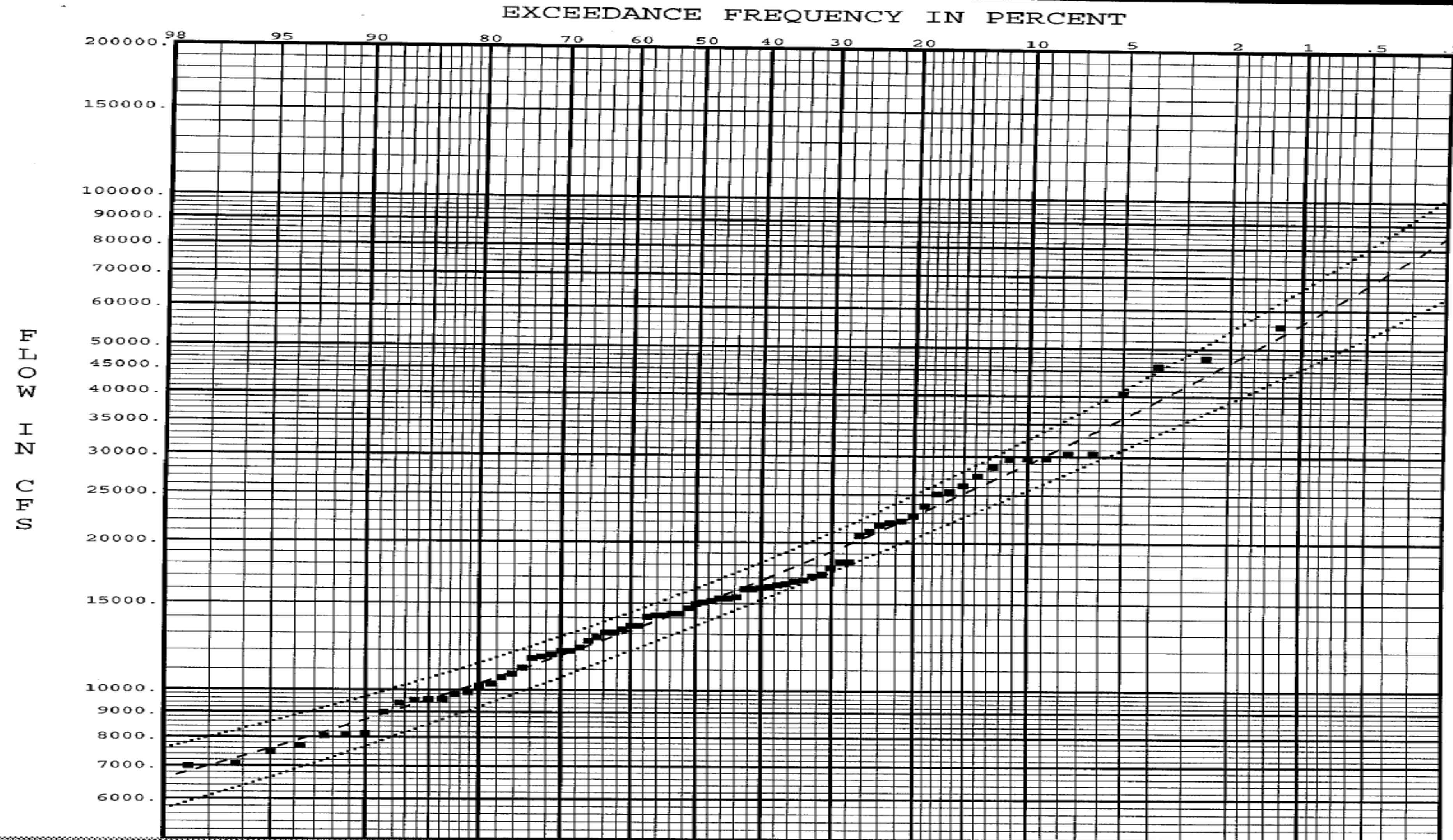
- Direct Analytical Approach

  When a sample of stream gage data and annual peak discharge data are available and can be fit with a statistical distribution. Uncertainty is attributed primarily to the probability distribution

- Analytical / Synthetic Approaches

  When the discharge-frequency function is derived from methods such as transfer, regression, empirical equations, and modeling simulations.

The example case in Montoursville, Pennsylvania used a **regional transfer** approach for hydrologic uncertainty



--- FLOW Frequency (with Exp. Prob.)
■ Weibull Plotting Positions
······· 5% and 95% Confidence Limits

FREQUENCY STATISTICS
LOG TRANSFORM OF FLOW, CFS

MEAN	4.1878	HISTORIC EVENTS	0
STANDARD DEV	.2032	HIGH OUTLIERS	0
SKEW	.5218	LOW OUTLIERS	0
REGIONAL SKEW	.4500	ZERO OR MISSING	0
ADOPTED SKEW	.5000	SYSTEMATIC EVENTS	79

NUMBER OF EVENTS

ANNUAL FLOOD PEAK FREQUENCY R
LOYALSOCK CREEK AT LOYALSOCKV
BASIN AREA = 435 SQ MI
WATER YEARS IN RECORD
1926-2004

Analytical Approaches

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Table 4-1
Procedures for Estimating Discharge-Probability Function Without Recorded Events (adapted from USWRC (1981))

Method	Summary of Procedure
Transfer	Discharge-probability function is derived from discharge sample at nearby stream. Each quantile (discharge value for specified probability) is extrapolated or interpolated for the location of interest.
Regional estimation of individual quantiles or of function parameters	Discharge-probability functions are derived from discharge samples at nearby gauged locations. Then the function parameters or individual quantiles are related to measurable catchment, channel, or climatic characteristics via regression analysis. The resulting predictive equations are used to estimate function parameters or quantiles for the location of interest.
Empirical equations	Quantile (flow or stage) is computed from precipitation with a simple empirical equation. Typically, the probability of discharge and precipitation are assumed equal.
Hypothetical frequency events	Unique discharge hydrographs due to storms of specified probabilities and temporal and areal distributions are computed with a rainfall-runoff model. Results are calibrated to observed events or discharge-probability relations at gauged locations so that probability of peak hydrograph equals storm probability.
Continuous simulation	Continuous record of discharge is computed from continuous record of precipitation with rainfall-runoff model, and annual discharge peaks are identified. The function is fitted to series of annual hydrograph peaks, using statistical analysis procedures.

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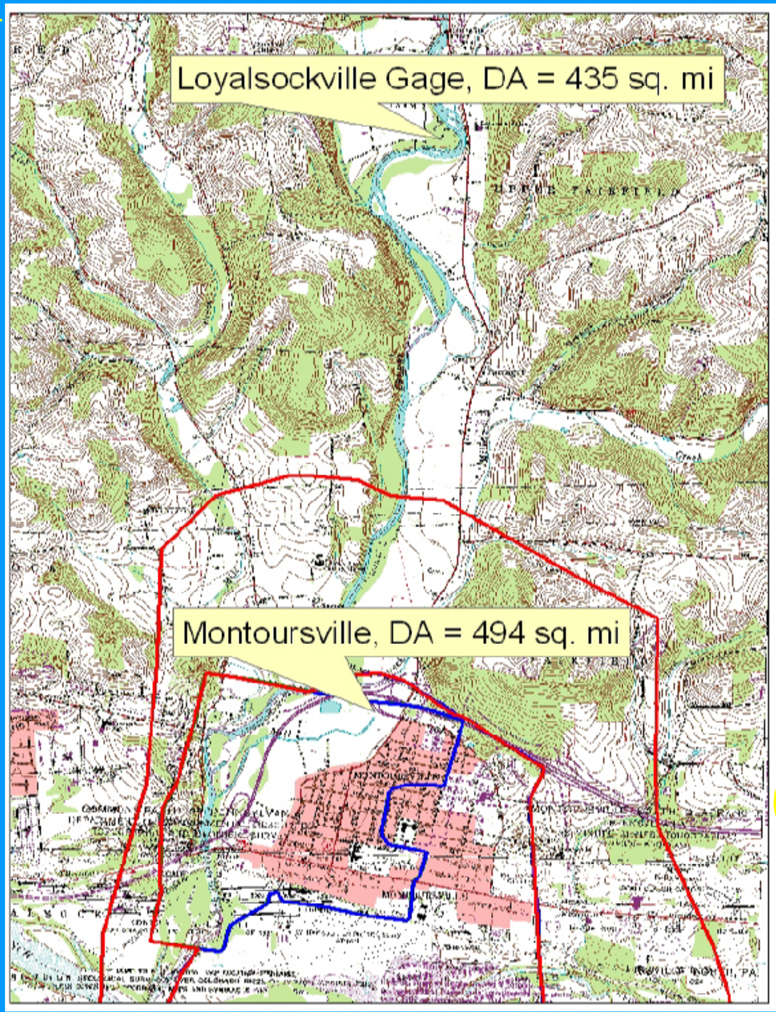
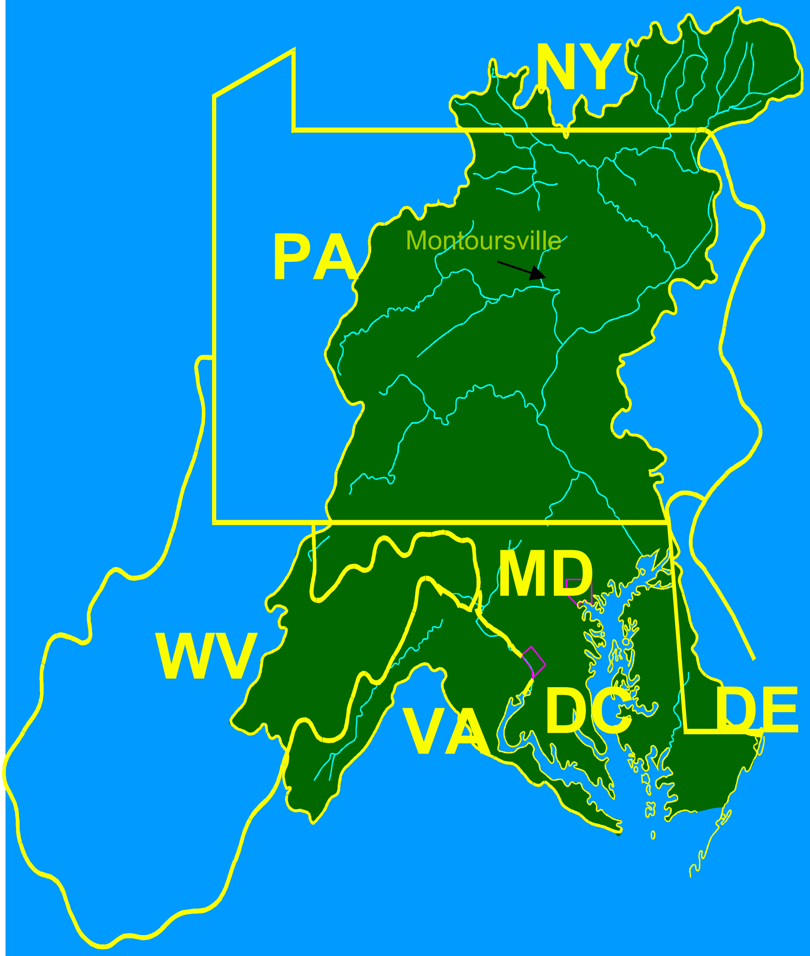
Analytical Approach: Regional Transfer

Montoursville, Pennsylvania





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Analytical Approach: Regional Transfer

Montoursville, Pennsylvania

- The flood frequency analysis from nearby Loyalsockville was available, but was located 5 miles upstream of Montoursville
- The drainage area ratio below was used to transfer the flows

$$\left(\frac{Q_M}{Q_L}\right) = \left(\frac{DA_M}{DA_L}\right)^{0.733}$$

, where the subscript M represents Montoursville and L represents Loyalsockville

- The results of the study below show the record length from Loyalsockville was reduced from 79 to 71 years.

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Analytical Approach: Regional Transfer

Montoursville, Pennsylvania

Montoursville Local Flood Protection Project: Hydrologic Routing					rem	
	20-Mar-03	Study		11-Feb-05	Study	
Recurrance	Loyalsockville	Montoursville		Loyalsockville	Montoursville	
Interval	Rte. 973			Rte. 973		
Drainage Area	435	494		435	494	
(sq. miles)						
1-year				6000	6559	
2-year				14800	16178	
5-year				22600	24704	
10-year	28500	31154		28900	31591	
20-year	35400	38696		36000	39352	
25-year				38500	42085	
50-year	45900	50174		46900	51267	
100-year	55300	60449		56500	61761	
500-year	83100	90838		85000	92915	
Ivan				40500	44271	
Agnes				47900	52360	
Hydrologic Risk and Uncertainty				15-Jul-05	rem	
Montoursville Flow is		114	percent of Loyalsockville's Flow			
Therefore, the Montoursville **Equivalent Record Length** is about					90	
percent of Loyalsockville's systematic record length,				79		
which equals	71					

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Analytical Approach: Regional Transfer

Montoursville, Pennsylvania

Table 4-5
Equivalent Record Length Guidelines

Method of Frequency Function Estimation	Equivalent Record Length[1]
Analytical distribution fitted with long-period gauged record available at site	Systematic record length
Estimated from analytical distribution fitted for long-period gauge on the same stream, with upstream drainage area within 20% of that of point of interest	90% to 100% of record length of gauged location
Estimated from analytical distribution fitted for long-period gauge within same watershed	50% to 90% of record length
Estimated with regional discharge-probability function parameters	Average length of record used in regional study
Estimated with rainfall-runoff-routing model calibrated to several events recorded at short-interval event gauge in watershed	20 to 30 years
Estimated with rainfall-runoff-routing model with regional model parameters (no rainfall-runoff-routing model calibration)	10 to 30 years
Estimated with rainfall-runoff-routing model with handbook or textbook model parameters	10 to 15 years

[1] Based on judgment to account for the quality of any data used in the analysis, for the degree of confidence in models, and for previous experience with similar studies.

Hydraulic Uncertainty

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- Uncertainties exist with stage-discharge functions because of measurement errors, the use of numerical models, and the inability of these models to exactly reproduce the complex nature of hydraulics. Therefore, uncertainty propagation studies must be performed for hydraulic parameters
- Hydraulic uncertainties are also handled differently for gaged reaches and ungaged reaches

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Hydraulic Uncertainty

Gaged Reaches

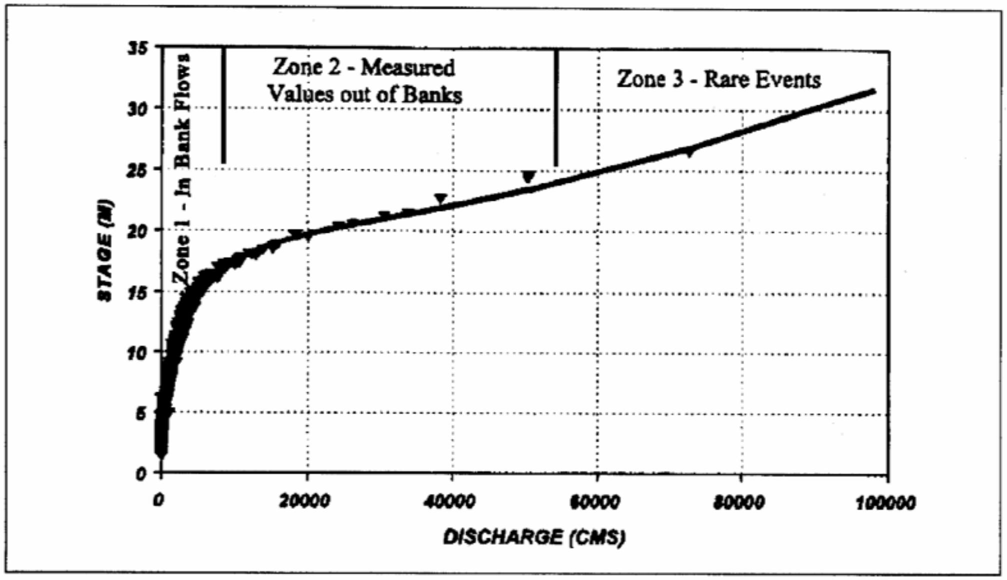

Figure 5-1. Stage-discharge plot showing uncertainty zones, observed data, and best-fit curve

The standard deviation defined by stage residuals determines the uncertainty for gauged reaches due to the nature of how the observed points fit the selected probability distribution.

Hydraulic Uncertainty

Ungaged Reaches

- For Ungaged reaches, uncertainty can be approximated from the Gamma Distribution. Figure 5-3 Below shows how this is done

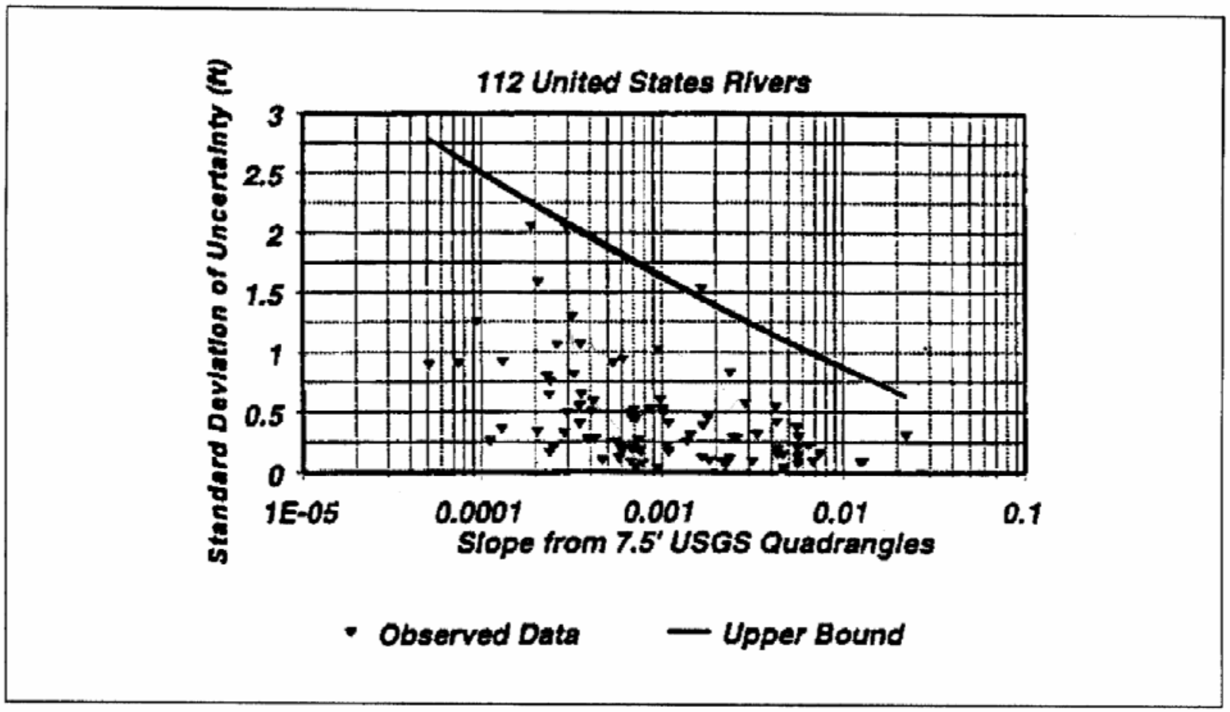

Figure 5-3. Stage-discharge uncertainty compared with channel slope from USGS 7.5-in. quadrangles, with upper bound for uncertainty

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Hydraulic Uncertainty

Ungaged Reaches

- For many ungaged areas, the hydraulic analysis is performed by computing water surface profiles. Uncertainties arise from the model's parameters. For the Montoursville case, uncertainties with Manning's "n" values, pier debris at bridges, and contraction/expansion coefficients were computed.
- A "Low Risk", an "Expected Risk", and a "High Risk" HEC-RAS model was produced for the Loyalsock Creek in Montoursville. Arbitrary increases in coefficients and parameters based on previous studies in the Baltimore District were chosen.
- The next slide shows the chosen parameters for the Montoursville hydraulic risk and uncertainty contribution

Hydraulic Uncertainty

Ungaged Reaches – Montoursville Study

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HEC-RAS Model Parameters for Low, Expected, and High Risk Scenarios

Coefficients of Contraction and Expansion

Location		Low	Expected	High
Contraction	Channel	0.1	0.1	0.3
	Bridge XS	0.3	0.3	0.5
Expansion	Channel	0.3	0.3	0.5
	Bridge XS	0.5	0.5	0.8

Pier Debris at Bridges

	Low	Expected	High
Pier Width increase	0%	25%	50% (max. 3 ft)
Lowering of Bridge Deck	0 ft.	0.5 ft	1.0 ft

Manning's n in Channels / Overbanks

(Next Slide)

Hydraulic Uncertainty

Ungaged Reaches – Montoursville Study

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Montoursville LFPP: Risk and Uncertainty Analysis --- Manning's n values								Percent Change		15	%	
+- 5% difference for n values												
				7.5	% Decrease					15	% Increase	
Edit Manning's n or k Values					Low Risk			Expected Risk			High Risk	
	River Station	Frctn (n/K)		n #1	n #2	n #3	n #1	n #2	n #3	n #1	n #2	n #3
1	10158.62	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
2	9802.355	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
3	9446.365	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
4	9038.917	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
5	8554.058	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
6	8122.26	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
7	7577.909	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
8	7219.518	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
9	6725.547	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
10	6326.275	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
11	6006.965	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
12	5715.366	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
13	5418.719	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
14	5207.008	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
15	4915.59	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
16	4703.012	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
17	4442.749	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
18	4187.805	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
19	3900.896	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
20	3713.969	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
21	3532.658	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
22	3276.832	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
23	3161.825	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
24	3040.741	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127
25	2929.254	n		0.093	0.040	0.102	0.100	0.043	0.110	0.115	0.049	0.127

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Hydraulic Uncertainty

Ungaged Reaches – Montoursville Study

Montoursville LFPP: Risk and Uncertainty Analysis			Results / Standard Deviation Computations						25-Mar-05 rem				
												Risk / Uncertainty Statistics	
			Low Risk			Expected Risk			High Risk				Estimated
												Stage	Standard
Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Difference (ft)	Deviation (ft)
Loyal_main	10158.62	100y	61761	525.93	540.04	61761	525.93	540.29	61761	525.93	540.97	0.93	0.23
Loyal_main	9802.355	100y	61761	524.1	538.05	61761	524.10	538.49	61761	524.10	539.42	1.37	0.34
Loyal_main	9446.365	100y	61761	522.19	537.05	61761	522.19	537.49	61761	522.19	538.41	1.36	0.34
Loyal_main	9038.917	100y	61761	520.17	536.42	61761	520.17	536.88	61761	520.17	537.77	1.35	0.34
Loyal_main	8554.058	100y	61761	520.38	535.95	61761	520.38	536.41	61761	520.38	537.30	1.35	0.34
Loyal_main	8122.26	100y	61761	519.59	535.54	61761	519.59	536.01	61761	519.59	536.92	1.38	0.34
Loyal_main	7577.909	100y	61761	516	534.47	61761	516.00	534.98	61761	516.00	535.90	1.43	0.36
Loyal_main	7219.518	100y	61761	515.78	533.32	61761	515.78	533.87	61761	515.78	534.80	1.48	0.37
Loyal_main	6725.547	100y	61761	515.12	531.41	61761	515.12	532.10	61761	515.12	533.11	1.70	0.43
Loyal_main	6326.275	100y	61761	514.14	529.61	61761	514.14	530.71	61761	514.14	531.88	2.27	0.57
Loyal_main	6006.965	100y	61761	513.31	529.22	61761	513.31	530.53	61761	513.31	531.75	2.53	0.63
Loyal_main	5715.366	100y	61761	512.56	529.24	61761	512.56	530.34	61761	512.56	531.54	2.30	0.57
Loyal_main	5418.719	100y	61761	511.8	529.25	61761	511.80	530.30	61761	511.80	531.48	2.23	0.56
Loyal_main	5207.008	100y	61761	506.86	529.38	61761	506.86	530.39	61761	506.86	531.51	2.13	0.53
Loyal_main	4915.59	100y	61761	502.43	529.25	61761	502.43	530.29	61761	502.43	531.38	2.13	0.53
Loyal_main	4703.012	100y	61761	501.11	529.25	61761	501.11	530.26	61761	501.11	531.36	2.11	0.53
Loyal_main	4442.749	100y	61761	501.69	529.19	61761	501.69	530.20	61761	501.69	531.30	2.11	0.53
Loyal_main	4187.805	100y	61761	507.87	529.05	61761	507.87	530.12	61761	507.87	531.22	2.17	0.54
Loyal_main	3900.896	100y	61761	506.95	528.56	61761	506.95	529.73	61761	506.95	530.84	2.28	0.57
Loyal_main	3713.969	100y	61761	506.32	528.22	61761	506.32	529.47	61761	506.32	530.59	2.37	0.59
Loyal_main	3532.658	100y	61761	505.81	527.99	61761	505.81	529.29	61761	505.81	530.41	2.42	0.60
Loyal_main	3276.832	100y	61761	505.79	527.42	61761	505.79	528.86	61761	505.79	529.98	2.56	0.64
Loyal_main	3161.825	100y	61761	505.76	527.44	61761	505.76	528.65	61761	505.76	529.77	2.33	0.58
Loyal_main	3040.741	100y	61761	505.71	527.03	61761	505.71	528.37	61761	505.71	529.51	2.48	0.62
Loyal_main	2929.254	100y	61761	505.66	526.87	61761	505.66	528.18	61761	505.66	529.31	2.44	0.61
Loyal_main	2802.688	100y	61761	505.6	526.72	61761	505.60	527.95	61761	505.60	529.08	2.36	0.59

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Hydraulic Uncertainty

Ungaged Reaches – Montoursville Study

Loyal_main	2619.493	100y	61761	505.28	526.58		61761	505.28	527.85		61761	505.28	529.01		2.43	0.61
Loyal_main	2504.836	100y	61761	504.83	526.45		61761	504.83	527.74		61761	504.83	528.91		2.46	0.61
Loyal_main	2420.983	100y	61761	504.51	526.37		61761	504.51	527.66		61761	504.51	528.82		2.45	0.61
Loyal_main	2219.247	100y	61761	499.78	526.3		61761	499.78	527.59		61761	499.78	528.71		2.41	0.60
Loyal_main	2089.226	100y	61761	499.3	526.17		61761	499.30	527.47		61761	499.30	528.59		2.42	0.61
Loyal_main	1862.067	100y	61761	503.38	526.07		61761	503.38	527.38		61761	503.38	528.46		2.39	0.60
Loyal_main	1692		Bridge				Bridge				Bridge					
Loyal_main	1538.278	100y	61761	504.56	525.43		61761	504.56	526.77		61761	504.56	527.72		2.29	0.57
Loyal_main	1462.307	100y	61761	502.39	525.38		61761	502.39	526.73		61761	502.39	527.66		2.28	0.57
Loyal_main	1419.472	100y	61761	502.48	525.32		61761	502.48	526.68		61761	502.48	527.60		2.28	0.57
Loyal_main	1320		Bridge				Bridge				Bridge					
Loyal_main	1211.046	100y	61761	501.77	524.47		61761	501.77	524.65		61761	501.77	525.66		1.19	0.30
Loyal_main	1155.62	100y	61761	502.09	524.29		61761	502.09	524.47		61761	502.09	525.47		1.18	0.30
Loyal_main	1100.197	100y	61761	503.28	524.11		61761	503.28	524.29		61761	503.28	525.27		1.16	0.29
Loyal_main	1029.615	100y	61761	503.74	524.05		61761	503.74	524.22		61761	503.74	525.19		1.14	0.29
Loyal_main	981.576	100y	61761	504.73	523.77		61761	504.73	523.94		61761	504.73	524.90		1.13	0.28
Loyal_main	952.636	100y	61761	504.73	523.79		61761	504.73	523.95		61761	504.73	524.89		1.10	0.28
Loyal_main	884.634	100y	61761	505	523.8		61761	505.00	523.95		61761	505.00	524.85		1.05	0.26
Loyal_main	802.63	100y	61761	505	523.24		61761	505.00	523.37		61761	505.00	524.03		0.79	0.20
Loyal_main	700		Bridge				Bridge				Bridge					
Loyal_main	623.907	100y	61761	504	522.77		61761	504.00	522.82		61761	504.00	523.04		0.27	0.07
Loyal_main	577.211	100y	61761	499.11	522.83		61761	499.11	522.87		61761	499.11	523.02		0.19	0.05
Loyal_main	510.647	100y	61761	498.41	522.8		61761	498.41	522.83		61761	498.41	522.96		0.16	0.04
Loyal_main	386.34	100y	61761	498.27	522.89		61761	498.27	522.91		61761	498.27	522.98		0.09	0.02
Loyal_main	324.825	100y	61761	499.07	522.82		61761	499.07	522.84		61761	499.07	522.89		0.07	0.02
Loyal_main	232.376	100y	61761	499.06	522.79		61761	499.06	522.80		61761	499.06	522.84		0.05	0.01
Loyal_main	150.779	100y	61761	498.94	522.79		61761	498.94	522.79		61761	498.94	522.81		0.02	0.00
Loyal_main	71.709	100y	61761	498.77	522.8		61761	498.77	522.80		61761	498.77	522.80		0.00	0.00
										(EM 1110-2-1619 Eq. 5-7)		**Mean ---------->**			**1.62**	**0.40**

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Hydrological and Hydraulic Contributions to Risk and Uncertainty Studies

- Hydrologic Uncertainty

Uncertainty with the Discharge – Probability Curve

- Hydraulic Uncertainty

Uncertainty with the Stage – Discharge Function

- Interior Flooding Uncertainty

Storm Runoff from the watershed that drains to the interior of a levee must be passed through or over the levee (EM-1110-2-1619). Performance of facilities like gravity outlets, pump stations, pump discharge outlets, collection facilities, storm sewers, and detention storage/flooding involves uncertainty

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Interior Flooding Uncertainty

- Optimal Process

Select four cases by identifying critical factors that define the best case, the Most-likely case, the worst-case, and a conservative case for interior facility Operation. Then, select a probability distribution to represent a likelihood of these scenarios (EM 1110-2-1619). The function should consider:

Table 7-1
Factors That Influence Interior-Area Facility Performance

- Number of pumps or the proportion of the total pumping capacity that remains if one or two pumps are inoperative.
- Reliability of the electrical power supply.
- Type and design of pumps.
- Configuration and design of the pumping station.
- Configuration and capacity of the associated ponding area and gravity outlets.
- Hydrologic and hydraulic characteristics of both the major (exterior) river basin and the interior watershed.
- Adverse weather conditions that may occur during a flood such as high winds, intense precipitation, hurricanes, or ice.
- Effectiveness of flood monitoring, forecasting, and warning systems.
- Institutional, organizational, financial, and personnel capabilities for maintaining and operating the project.
- Perceived importance of the closure.

Interior Flooding Uncertainty

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- Optimal Process

And the result should look like the following:

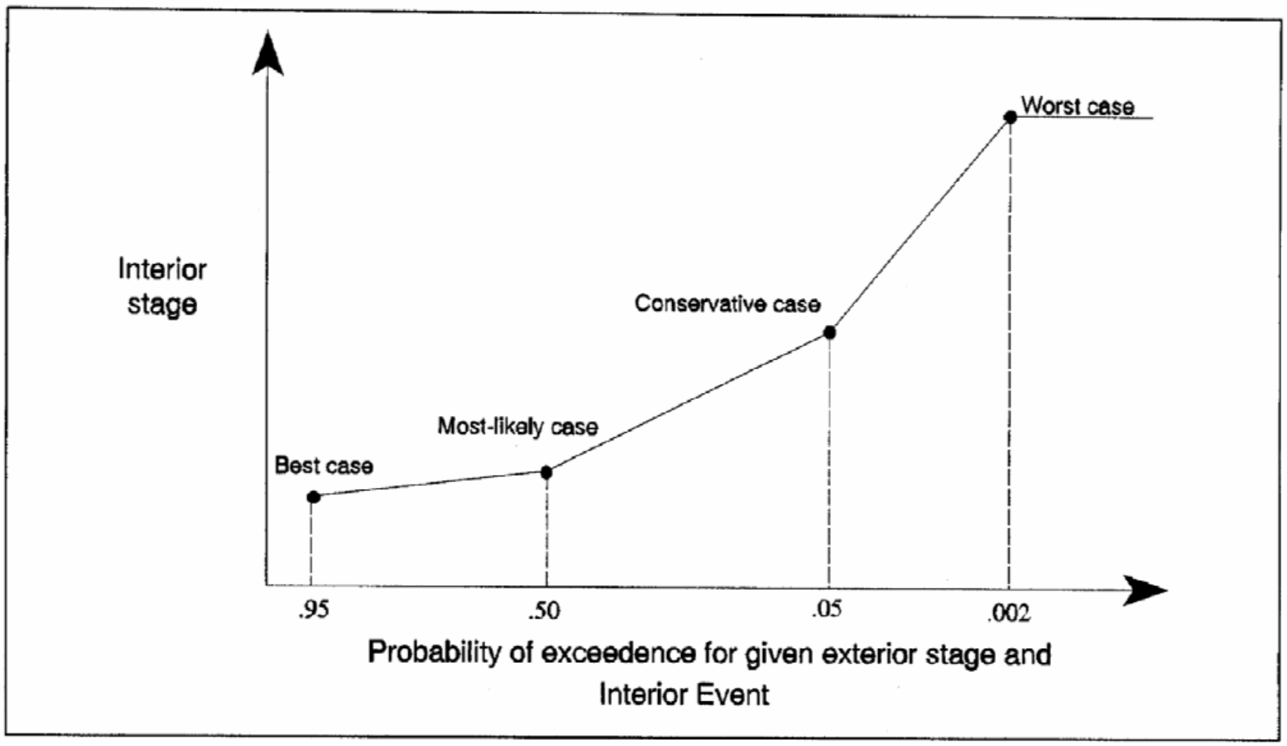

Figure 7-5. Probability function representing interior-stage uncertainty

Interior Flooding Uncertainty

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- Optimal Process

An annual exceedance curve for error probability similar to that from the HEC-FFA analysis would then be generated:

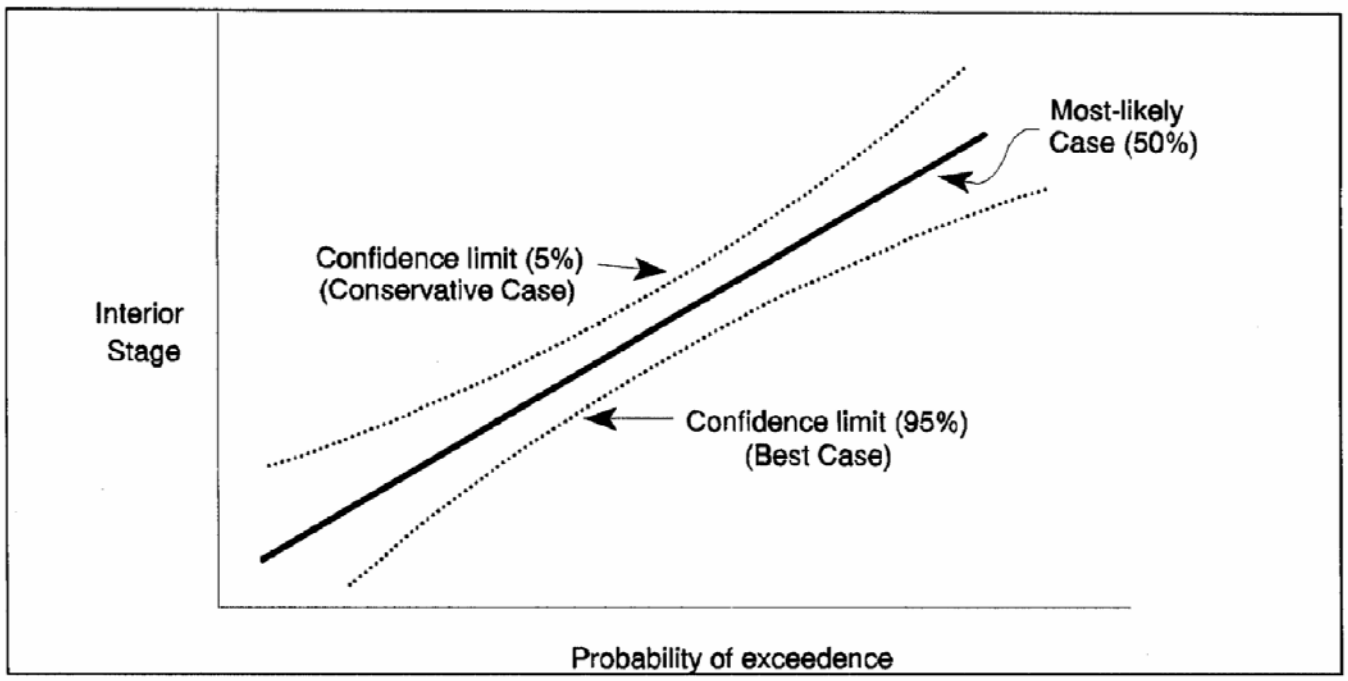

Figure 7-6. Example interior stage-exceedance probability function

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Interior Flooding Uncertainty

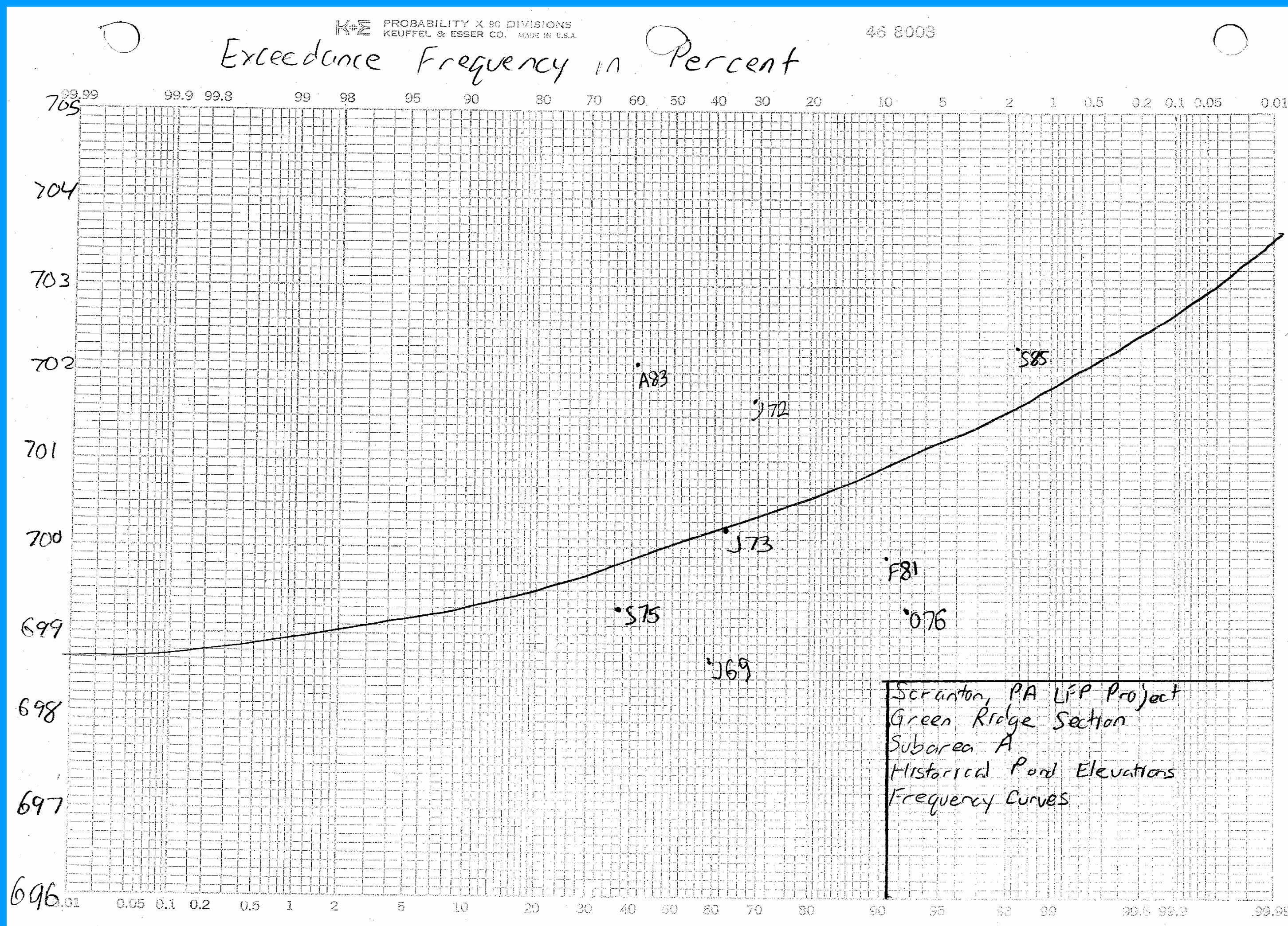
- Optimal Process

This process would be repeated for a range of values for exterior stage.

However, a study performed earlier

Indicated the best-fit curve did not fit well through points.

Interior Flooding Uncertainty



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Interior Flooding Uncertainty

Presently, there is no standard automated way to perform Interior Flooding analyses and their contributions to risk and uncertainty analyses. Presently used expensive procedures could be more efficient.

Standard procedure:

- HEC -1 for Hydrology and HEC-IFH / INTDRA3 for flooding analysis

Recommendation

- I believe in updating and merging HEC-IFH functionality into HEC-HMS and adding automated risk/uncertainty functionality compliant with EM 1110-2-1619 and EM 1110-2-1413, perhaps even an interior sub area delineation feature or something for HEC-GeoHMS

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Example Results

Table 9-13
Present Economic Benefits of Alternatives

Plan	Annual With-Project Residual Damage, $1000's	Annual Inundation Reduction Benefit, $1000's	Annual Cost, $1000's	Annual Net Benefit, $1000's
Without project	78.1	0.0	0.0	0.0
6.68-m levee	50.6	27.5	19.8	7.7
7.32-m levee	39.9	38.2	25.0	13.2
7.77-m levee	29.6	48.5	30.6	17.9
8.23-m levee	18.4	59.7	37.1	22.6
Channel modification	41.2	36.9	25.0	11.9
Detention basin	44.1	34.0	35.8	-1.8
Mixed measure	24.5	53.6	45.6	8.0

Table 9-14
Annual Exceedance Probability and Long-term Risk

Plan	Median Estimate of Annual Exceedance Probability	Annual Exceedance Probability with Uncertainty Analysis	Long-term Risk		
			10 yr	25 yr	50 yr
6.68-m levee	0.010	0.0122	0.12	0.26	0.46
7.32-m levee	0.007	0.0082	0.08	0.19	0.34
7.77-m levee	0.004	0.0056	0.05	0.13	0.25
8.23-m levee	0.002	0.0031	0.03	0.08	0.14
Channel modification	0.027	0.031	0.27	0.55	0.79
Detention basin	0.033	0.038	0.32	0.62	0.86
Mixed measure	0.014	0.016	0.15	0.33	0.55

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Summary

- Hydrologic and Hydraulic uncertainty needs to be properly studied to account for risk and make better informed decisions with flood situations.
- Current methodology accounts for uncertainty in most hydrologic and hydraulic parameters, EXCEPT

The ability to account for interior flooding uncertainties is still not straightforward at this time and a statistical software add-on in addition to updates to current interior flooding analysis packages would be recommended.