WE BRING IT ALL TOGETHER

Chickamauga Lock and Dam
Lock Addition
Cofferdam Height Optimization Study

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ENERGY WATER INFORMATION GOVERNMENT

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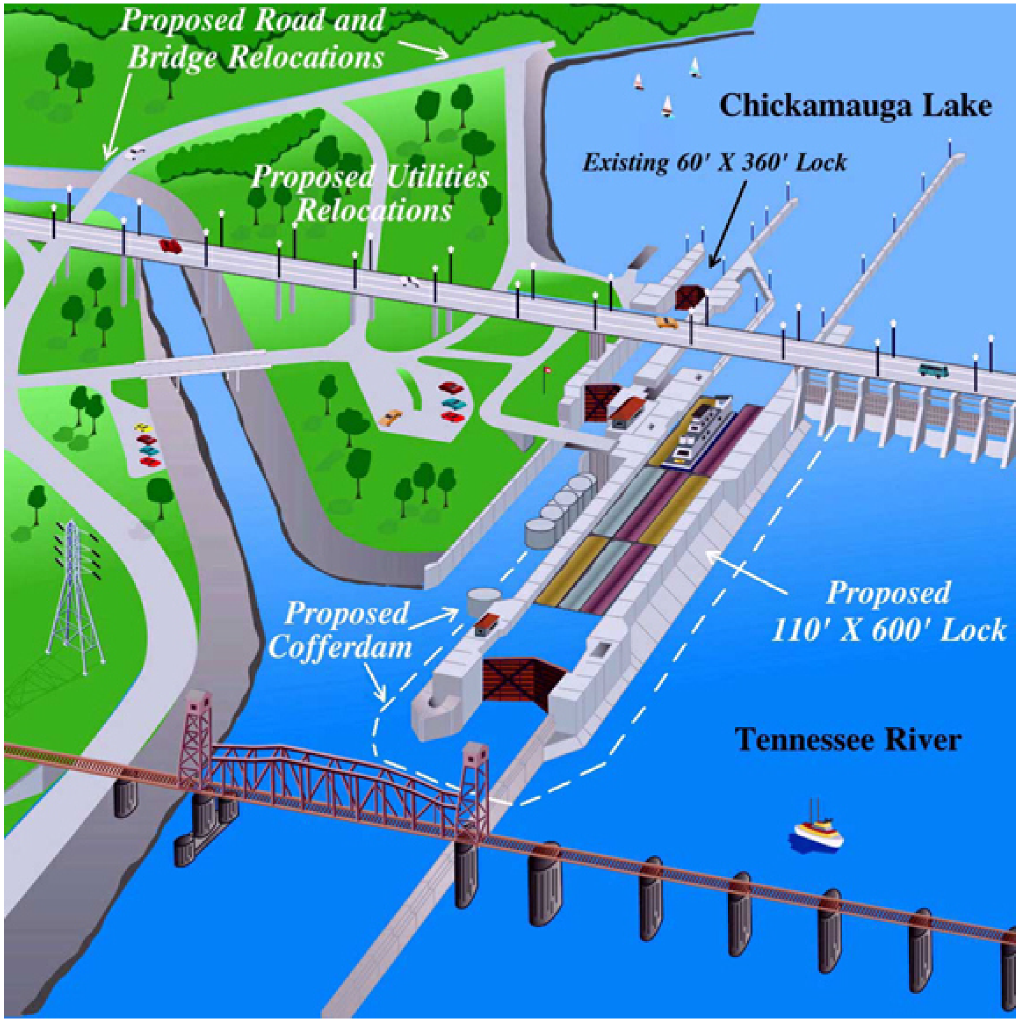
Cofferdam Height Optimization Study
Agenda

- Background - Lock Replacement Study
- Cofferdam Risk and Uncertainty (R&U) Approach – EM1605 (hand method) vs. Monte Carlo Simulation
- R&U Inputs
- R&U Results

Background - Lock Replacement Study

Nashville District and Tennessee Valley Authority Performed Feasibility Study and Determined In-The-Dry Construction for Lock Replacement

Chickamauga Lock Replacement Background



- USACE Nashville District and the Tennessee Valley Authority Performed Lock Replacement Study
- Lock is to be Replaced Due to Existing Lock Stability Concerns
- Determined that in the Dry Construction is Most Desirable

Cofferdam Height

- TO WHAT HEIGHT SHOULD COFFERDAM BE CONSTRUCTED?
- WHAT METHOD SHOULD BE USED TO ANSWER THIS QUESTION?

Cofferdam Starting Parameters

Given Information Regarding Cofferdam Height Optimization	
Top of Cofferdam (feet)	Equivalent Return Period (years)
655.2	10
658.5	25
661.8	100

Three different construction periods for lock addition were considered: 5, 7, & 10 years.

Cofferdam Risk and Uncertainty (R&U) Approach – EM 1110-2-1605 (hand method) vs. Monte Carlo Simulation

EM 1605 (Hand Method) is Limited in Prediction of Risk Costs, While Monte Carlo Simulation Allows for More Versatility in Prediction of Risk Costs

Risk Cost Equation

- Cofferdam Height Optimization Equation Can be Simplified Into:

Risk Cost = RC = *P* * Flood Damage Costs

+ Construction Cost

- The Derivation or Determination of P is Where Monte Carlo Simulation Allows for Greater Advantage Over the EM 1605 (Hand Method)

EM 1110-2-1605 – Derivation of *P*

- Risk of Flooding is Defined as:

$$P = \frac{N! \cdot p^{i} \cdot (1 - p)^{N-i}}{i! \cdot (N - i)!}$$

Where:

- ✓ *N = Construction Period*
- ✓ *i = Number of Occurrences of Specific Flood Return Period*
- ✓ *P = Probability of Obtaining During Construction Period Exactly i Events of Specific Flood Return Interval Having a Probability of p Occurring in a Single Trial.*

- Problem is There is no Reasonable "Hand Method" for Determining "i".

EM 1110-2-1605 – Simplification of *P*

- Solution - Use Statistics to Simplify Equation
- Solve Opposite Question – What is Probability No Floods Occur? i.e. i = 0

$$P = (1 - p)^N$$

Where:

- ✓ *P = probability of obtaining during construction period no flood events having a probability of p*

- Now 1 - P = Probability of Obtaining at Least One Event of Probability p During Construction Period.
- The result does not define how many events (i.e. Could be More Than 1)

Monte Carlo Simulation – Prediction of *P*

- Monte Carlo Simulation Allows for Prediction of “i”.
- “i” is Predicted by Treating Annual Frequency Curve as Independent Predictor of Flood Events for Each Year of Construction Period
- This is Accomplished by Fitting a Probability Distribution to Annual Frequency Curve

Monte Carlo Simulation – Prediction of *P*

- Thus the Monte Carlo Simulation Model can Provide One or More Tailwater Elevations Above the Cofferdam Height During a Construction Period
- Cost Equations were Then Adjusted to Allow for Flooding Costs that Result From More Than One Event to be Added to the Total Risk Cost (Construction + Flooding Costs).
- RC = Sum (Flood Cost_i + Construction Cost)
  - ✓ Where i = number of floods

R&U Inputs

Identification of Uncertainty and Assignment of Probability Distributions

Monte Carlo Simulation – Prediction of *P*

- The inputs include:

✓ cofferdam cell height (constant),

✓ construction duration (entered as discrete values),

✓ tailwater frequency curve (cumulative/beta general distributions),

✓ tailwater duration curve (constant per specific flood event),

✓ flooding costs (triangular distribution),

✓ construction costs (triangular distribution).

- The output includes:

✓ total risk cost (triangular distribution).

Annual Tailwater Frequency Curve Data From 1958 to 1999

Percent Chance Exceedance	(Return Interval in Years)	(Elevation in feet) Expected Probability
0.2	(500 - year)	665.75
1	(100 - year)	661.79
2	(50 - year)	659.96
5	(20 - year)	657.35
10	(10 - year)	655.16
20	(5 - year)	652.63
50	(2- year)	648.09

Corrected Flood Probabilities For EM 1605 (Hand Method)

Percent Chance Exceedance	*(Return Interval in Years)*	*(Elevation in feet) Expected Probability*	**Probability of at least one or more flood events during construction period**		
			5 yrs	**7 yrs**	**10 yrs**
0.2	(500 - year)	665.75	**1.0%**	**1.4%**	**2.0%**
1	(100 - year)	661.79	**4.9%**	**6.8%**	**9.6%**
2	(50 - year)	659.96	**9.6%**	**13.2%**	**18.3%**
5	(20 - year)	657.35	**22.6%**	**30.2%**	**40.1%**
10	(10 - year)	655.16	**41.0%**	**52.2%**	**65.1%**
20	(5 - year)	652.63	**67.2%**	**79.0%**	**89.3%**
50	(2- year)	648.09	**96.9%**	**99.2%**	**99.9%**

Cofferdam Construction Cost – Probability Distribution

T.O. COFFERDAM ELEVATION	Construction Cost	Construction Cost w/ Contingencies		
	BASE (w/o Contingency)	MIN %	AVG %	MAX%
655.2 (10 yr)	$24,072,499	$27,940,842	$29,763,812	$31,594,681
658.5 (25 yr)	$25,835,790	$29,953,783	$31,890,153	$33,835,602
661.8 (100 yr)	$27,261,317	$31,582,069	$33,612,552	$35,652,531

Cofferdam Construction Cost – Measurement of Uncertainty

Item No.	Description	% of Contingency		
		Min %	Avg %	Max %
1	Mob/Prepatory	2	3	5
2	Cofferdam Cells	15	20	25
3	Ramp Cells	15	20	25
4	Tie-Ins	30	45	60
5	Flooding Facility	20	30	40
6	Dewatering	30	35	40
7	Instrumentation	20	35	50
8	Miscellaneous	20	35	50
9	Cofferdam Removal	15	23	30

Cofferdam Construction Cost – Mitigation of Bias

Item No.	Description	% of Contingency			Team Member
		Min %	Avg %	Max %	
4	Tie-ins to Existing Facilities	2	3	4	G. Hicks
		20	25	30	L. Schieber
		30	40	50	J. Koontz
	Participated in discussion				M. Ledbetter
	Selected Values	**30**	**45**	**60**	

Cofferdam Flood Cost – Probability Distribution

	Total Fixed Flood Cost	Total Fixed Flood Costs w/ Contingencies		
T.O. COFFERDAM ELEVATION	BASE (w/o Contingency)	MIN %	AVG %	MAX%
655.2 (10 yr)	$4,533,977	$5,353,413	$5,794,580	$6,235,746
658.5 (25 yr)	$4,682,352	$5,677,143	$6,141,266	$6,605,389
661.8 (100 yr)	$4,865,427	$5,729,313	$6,195,062	$6,660,811

Cofferdam Flood Cost – Measurement of Uncertainty

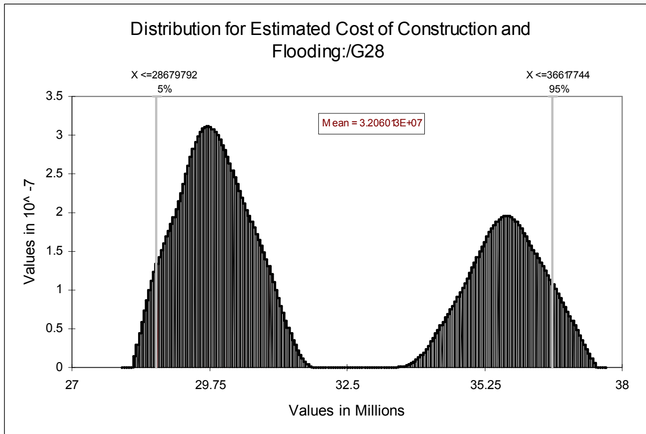
Item No.	Description	% of Contingency		
		Min %	Avg %	Max %
1	Pumping	10	15	20
2	Cleanup	20	35	50
3	Downtime	20	30	40
4	Damage	20	35	50

R&U Results

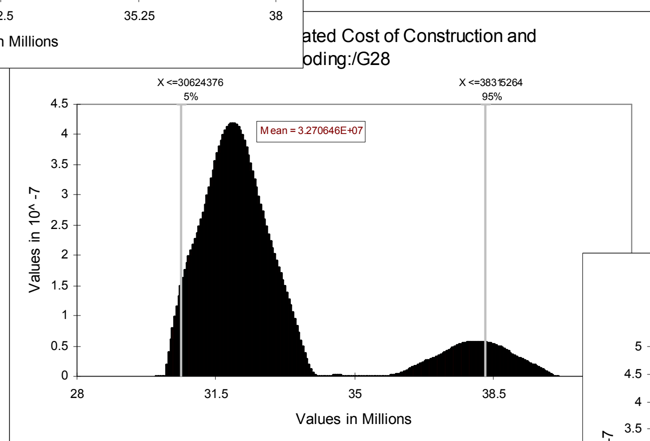
EM 1110-2-1605 Results Suggest The Optimum Cofferdam Height is the Lowest Elevation,

The Monte Carlo Simulation Results Suggest the Optimum Cofferdam Height is the Middle to Tallest Elevation Depending Upon Construction Duration

EM 1605 – Risk Cost Results

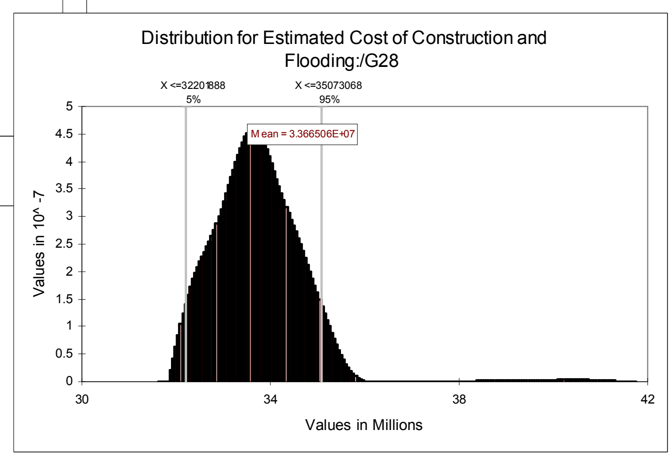


Cell Height 655.2

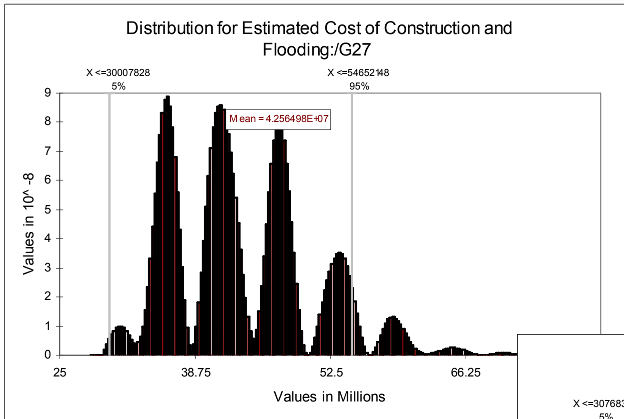


Cell Height 658.5

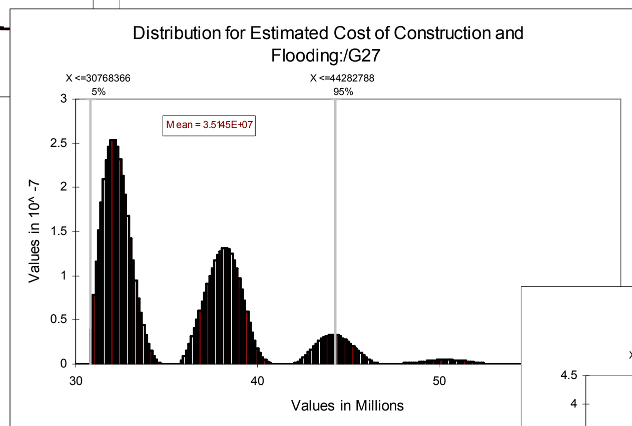
Cell Height 661.8



Monte Carlo Simulation – Risk Cost Results



Cell Height 655.2



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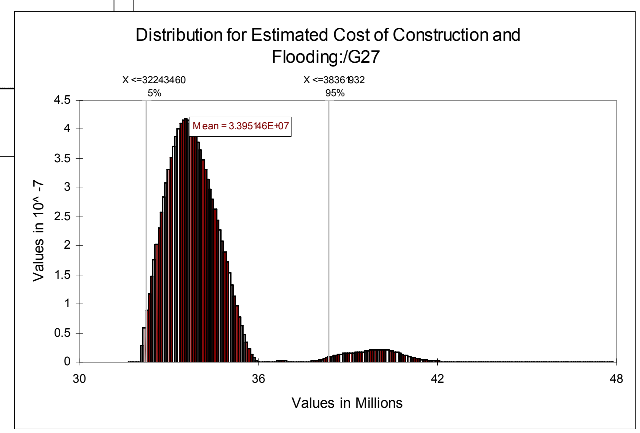
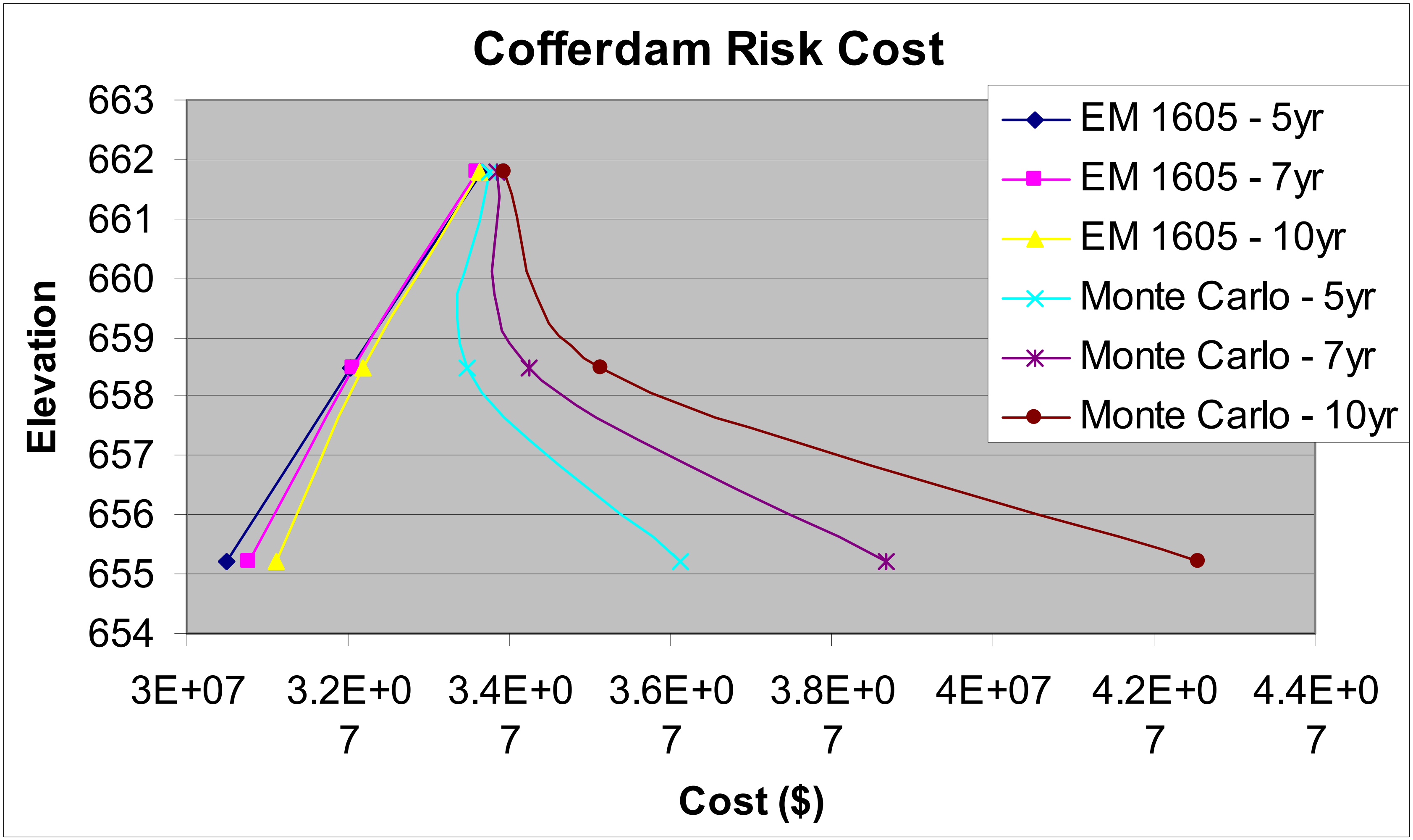


Comparison of Risk Cost

Cofferdam Height Optimization Results for EM 1605-10 Year Construction Period											
Top Elevation of Cofferdam (ft)	Equivalent Return Period (yr)	Total Flooding Cost, Mean ($)	90% Confidence Interval for Total Flooding Cost Mean ($)		Total Construction Cost, Mean ($)	90% Confidence Interval for Mean Total Construction Cost Mean ($)		**Total Risk Cost, Mean ($)**	**90% Confidence Interval for Mean of Total Risk Cost ($)**	
			5%	95%		5%	95%		**5%**	**95%**
655.2	10	1350796.74	0	4867541.5	29767114	28521360	31018496	**31117243**	**28680974**	**34852772**
658.5	25	292081.072	0	2475259.75	31884883	30577972	33197282	32185256	30618184	34375240
661.8	100	9451.18353	0	0	33608618	32234220	35005512	33625169	32227414	35026244

Cofferdam Height Optimization Results for Alternate Method-10 Year Construction Period										
Top Elevation of Cofferdam (ft)	Equivalent Return Period (yr)	Total Flooding Cost, Mean ($)	90% Confidence Interval for Mean of Total Flooding Cost ($)		Total Construction Cost, Mean ($)	90% Confidence Interval for Mean of Total Construction Cost Mean ($)		**Total Risk Cost, Mean ($)**	**90% Confidence Interval for Mean of Total Risk Cost ($)**	
			5%	95%		5%	95%		**5%**	**95%**
655.2	10	12798011.6	0	23954028	29766965	28519440	31012780	42564976	30007828	54652148
658.5	25	3246614.75	0	12351337	31898379	30560092	33215586	35144994	30768366	44282788
661.8	100	336133.295	0	5867248.5	33615328	32221876	35006436	**33951461**	**32243460**	**38361932**

Summary of Risk Cost



Questions ?

Used Monte Carlo Simulation as a Tool to Predict Risk Cost and Provide Information Regarding Risk Management. Compared this with EM 1110-2-1605 (Hand Method).

Contact Information

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