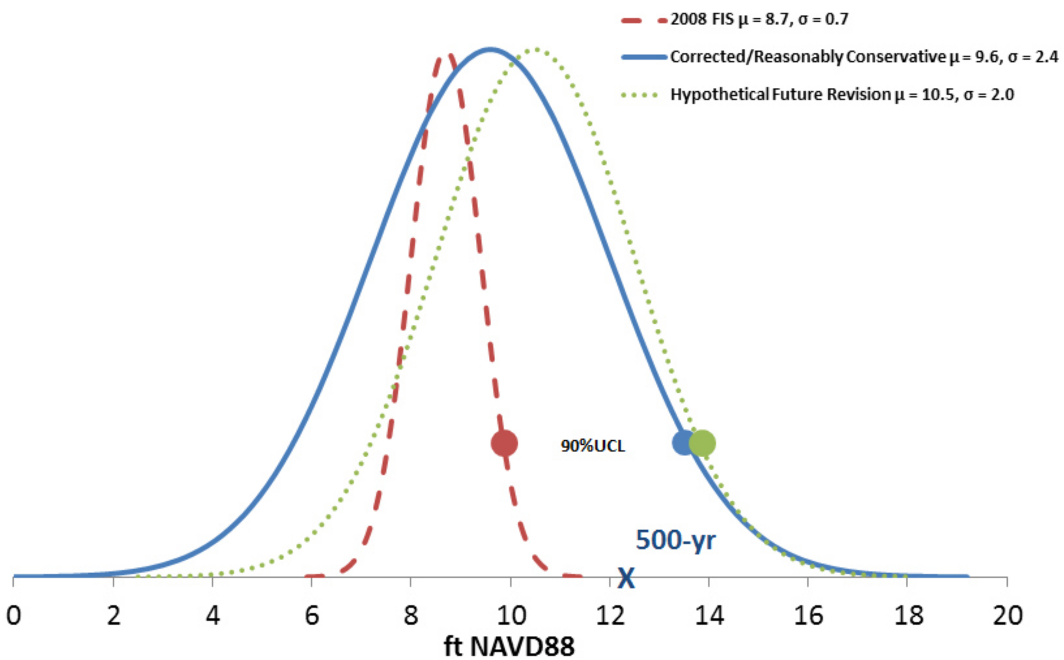
New Orleans
Hurricane Surge Risk Management

Part IV. Post-Katrina Surge Hazard Estimate



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June 2015

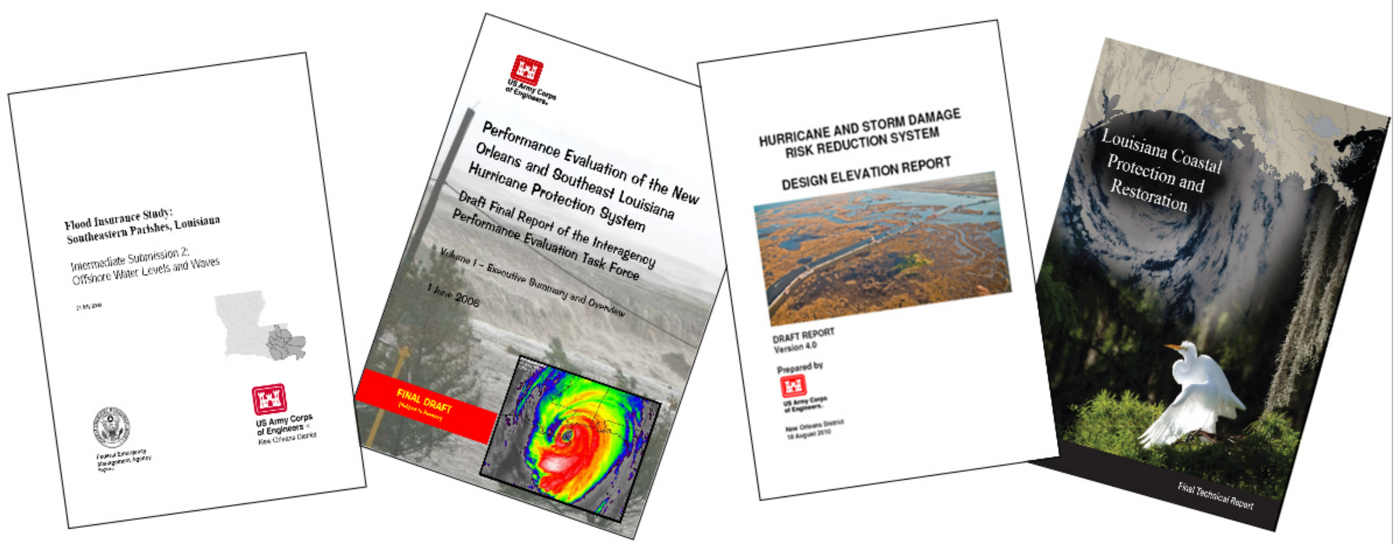
Part IV. Topics

- 2008 NFIP FIS Surge Hazard Analysis
- Modified 100- & 500-yr Surge Estimates
- 100- and 500-yr Surge Estimates
- Comparison of Pre- and Post-Katrina Surge Hazards
- Katrina Surge Return Period
- General Limitation
- 10 Significant Issues
- Surge Hazard Estimate Uncertainty
- Independent Exposures
- Future Reduction of Surge Hazard Uncertainty
- Revising Surge Hazard Analysis

2008 NFIP FIS Surge Hazard Analysis

Revised NFIP FIS one of 6 parallel USACE post-Katrina efforts; others:

- Support for IPET forensic investigations.
- Design & construction of a protection system for the 100-yr surge—known as the Hurricane & Storm Damage Risk Reduction System (HSDRRS)—for NFIP accreditation.
- Design of HSDRRS resiliency to address 500-yr surge.
- IPET polder inundation residual risk evaluation.
- *Louisiana Coastal Protection & Restoration (LaCPR)* Study of



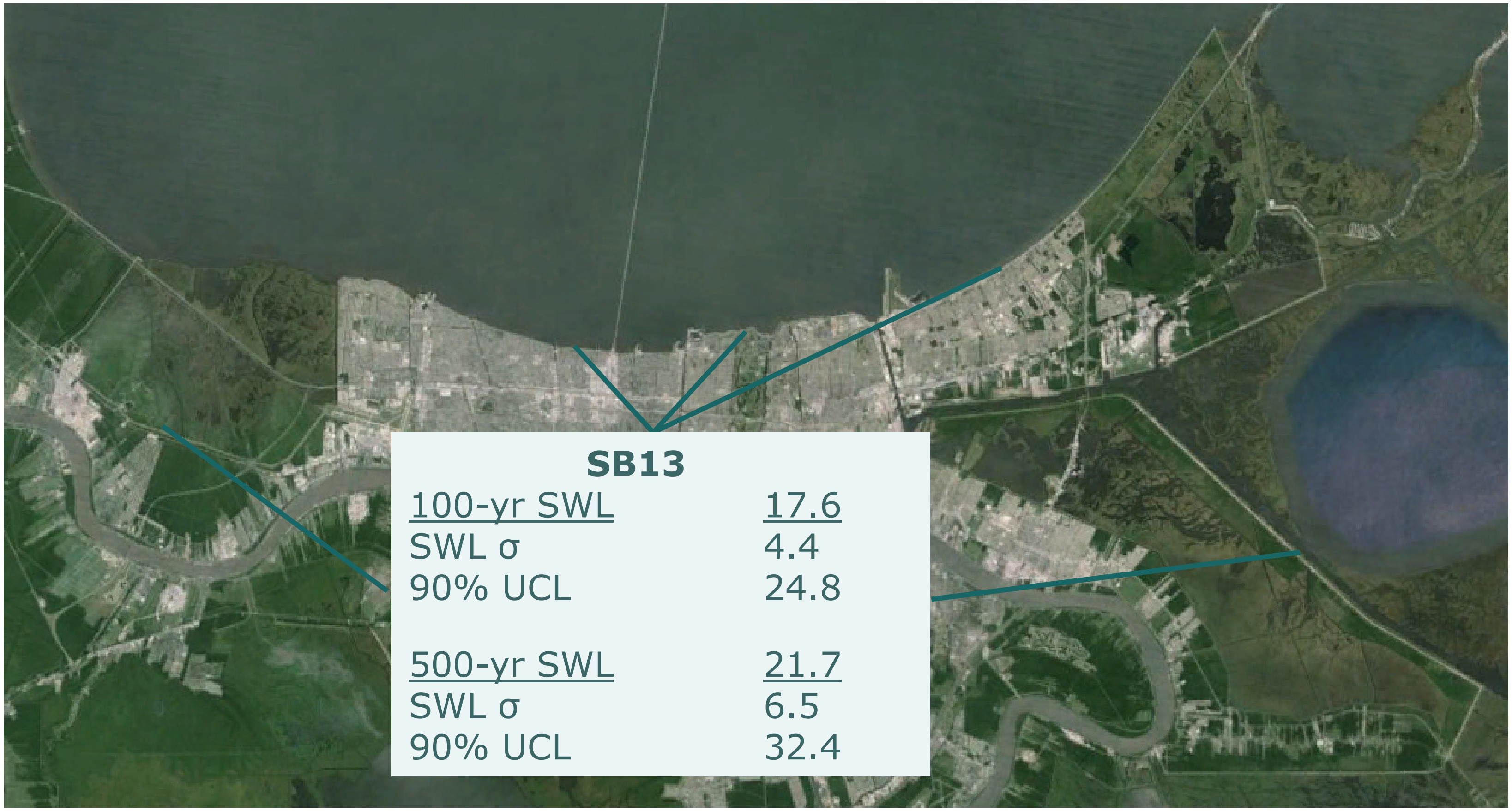
2008 NFIP FIS Surge Hazard Analysis

- During these efforts the USACE led and/or funded many surge science advances .
- USACE integrated these into the NFIP FIS surge hazard analysis—completed between 2005 and mid-2008.
- Employed:
  - Katrina validated HPC/High-Resolution ADCIRC+STWAVE model (loose coupling),
  - Resio Surge-Response OS approach to JPM,
  - OS of 152 storms
- The USACE's approach to the SELA FIS contributed greatly to practices followed & refined in the ten ensuing FISs across the Gulf & Atlantic Coasts.

Modified 100- & 500-yr Surge Estimates

- Published FIS estimates reflect “small” errors in USACE FORTRAN code used to compute surge hazard curve.
  - Bob Jacobsen PE, *Four Priority Issues with the USACE Surge Hazard and HSDRRS Overtopping Analysis*, prepared for SLFPA-E and CPRA, March 2015.
  - Woods Hole Group *Technical Memorandum* (for Lonnie G. Harper & Assoc.) for CPRA, 2015.
- Corrected estimates are <1 ft higher than published FIS estimates.
- **For residual risk management purposes it is appropriate to used corrected estimates.**
- Corrected estimates are referred to as FIS estimates since they were derived with the FIS SOP.

100- & 500-yr Surge ft NAVD88



Pre- vs Post-Katrina

NO Lakefront—NO01

- Post-Katrina 100-yr estimate is 0.2 ft lower than the pre-Katrina (1966) estimate.
- Nominal 500-yr estimate is only 0.8 ft higher—adjusting to surge depth.
- Considering wave contribution to setup the new 100-yr surge is closer to a foot lower, & the 500-yr estimates are almost identical.
- USACE estimates are even lower without correction.

Pre-Katrina	**ft MSL (NGVD)**	**Above LML**
Local Mean Level	1.0	
SPH	11.5	10.5
100-yr	10.3	9.3
500-yr	11.9	10.9
Post-Katrina	**ft NAVD88**	**Above LML**
Local Mean Level	0.5	
Katrina Actual	11.8	11.3
100-yr	9.6	9.1
500-yr	12.2	11.7

Uncorrected USACE 100-yr is 8.7 ft NAVD88 or 8.2 ft above LML.

Pre- vs Post-Katrina

MRGO (Bayou Dupre)—SB13

- Post-Katrina analysis increases 100- & Nominal 500-yr hazard estimates substantially—almost 5 & 7 ft, respectively

Pre-Katrina	**ft MSL (NGVD)**	**Above LML**		
Local Mean Level	0.9			
SPH	13	12.1		
100-yr	12.5	11.6		
500-yr	13.7	12.8		
Post-Katrina	**ft NAVD88**	**Above LML**	**ft NAVD88**	**Above LML**
Local Mean Level	0.3			
Katrina Actual	19.5	19.2		
	Without IHNC Barrier		*With IHNC Barrier*	
100-yr	16.7	16.4	17.6	17.3
500-yr	19.9	19.6	21.7	21.4

Pre- vs Post-Katrina

Larger spread between 100- & 500-yr hazards in the post-Katrina versus the pre-Katrina (1966) estimates at both locations:

- NO Lakefront—2.6 vs 1.6 ft
- MRGO (without the IHNC Barrier)— 3.2 vs 1.2 ft.

Katrina Surge Return Period

According to FIS analysis Katrina's surge at NO Lakefront & MRGO was :

- 2.2 & 2.8 ft above new 100-yr level (respectively).
- 0.4 ft below Nominal 500-yr level (both).

Corresponds to roughly a 400-yr event for both locations (using a log-linear interpolation).

The FIS analysis thus suggests that Katrina's surge should be regarded as an extremely unlikely event.

General Limitation

NFIP Programmatic Constraints

- The emphasis on the 100-yr hazard.
  - Other hazard level estimates have a much lower priority.
  - 500-yr surge—should be regarded as "**Nominal**."
- Tolerance for some regional error—HPC/High Resolution Surge Models are ***not currently calibrated***.
- Tolerance for more localized error
  - FIS SOP tends to focus almost exclusively on regional error.
  - FIS budget & schedule constraints mean that localized error reduction is often sacrificed.
- Similarly, localized differences in uncertainty tend not to be a subject of the FIS SOP.
- Uncertainty not used at all in flood zone delineation.
- Some political & institutional interests may favor under- versus over-estimated 100-yr flood elevations.

General Limitation
NFIP Programmatic Constraints

- Most communities:
  - Highly sensitive to impacts of flood zones on community economic stability & growth.
  - Monitor FIS' closely for overestimation errors.
  - Less concerned with underestimation errors.
- However, flood risk managers (especially urban):
  - Must plan for catastrophic concerns well beyond those of the NFIP—loss of life, uninsured property, economic well-being, way-of-life.
  - Must address extreme risks to a specific community's population, & critical economic & cultural resources.
  - Demand higher quality estimates of 100-yr, 500-yr, & greater hazards.
  - Also demand a higher quality assessment of uncertainties.
  - ***Moreover to ensure an adequate FOS in design, local projects for reducing risk beyond the NFIP require <u>reasonably conservative estimates of uncertainties</u>.***

10 Significant Issues—Overview

- Importantly, these issues are treated differently under SOPs for NFIP FISs versus local residual risk management—given different priorities and constraints.
- Issues result in large part from continually improving understanding of hurricane climatology, surge physics, surge modeling, & JPMs.
- Potential magnitude of surge uncertainty associated with each issue can be treated for convenience as Normally Distributed.
- Characterized with standard deviation (σ); each can exceed 10%.
- σ values are added in quadrature; 10 combined can easily exceed 25% at sensitive locations

Issues 1 thru 4

- These are addressed in the JPM ***epsilon*** term.
- But 1 & 2—surge model hindcast & tides—prone to local variations; typically ignored in a regional FIS; important for local residual risk reduction.
- Interestingly, FIS for Southeast Louisiana actually documented a notable hindcast ***under-prediction bias*** along the NO Lakefront.

Factor	Potential Surge σ	Evaluation of σ	FIS SOPs	Localized Variation?	Local Residual Risk Reduction SOP
1. General accuracy and precision of HPC/High-Resolution surge model	>15%	Residual error from hindcast validation.	Region-wide uniform σ included in epsilon.	Yes	Evaluate hindcast bias and precision at a sub-regional scale and adjust epsilon or include in CI
2. Timing of tides	<0.3 ft	Tidal analysis.		Yes	Adjust for local tide range.
3. Wind-field shape (Holland B)	>10%	Holland B surge-response analysis indicates direct effect on surge		No	Same as NFIP.
4. Additional wind-field characteristics (e.g., banding)	>5%	Residual error between surge modeling with high resolution wind fields versus the simpler wind-fields.		No	

Issues 5 thru 8

- Issues 5 - 8 tend to be highly localized, with local values of σ for 5, 6, & 7 currently requiring professional judgment.
- σ values have not been a subject of the FIS SOP but would be important to local residual risk reduction.
- 5, 6 & 7 could be important sources of Surge-Response underestimation bias for large, shallow, inland lakes & bays.

<table>
<tr><th>Factor</th><th>Potential Surge σ</th><th>Evaluation of σ</th><th>FIS SOPs</th><th>Localized Variation?</th><th>Local Residual Risk Reduction SOP</th></tr>
<tr><td>5. Pre-storm setup and rainfall accumulations in interior lakes and bays</td><td>>10%</td><td>Requires professional judgment.</td><td rowspan="4">Not currently addressed.</td><td>Yes</td><td rowspan="4">Include a reasonably conservative factor in CI</td></tr>
<tr><td>6. Empirical representations of hydrodynamic and wind-water drags at sensitive locations</td><td>>10%</td><td>Requires professional judgment.</td><td>Yes</td></tr>
<tr><td>7. OS representativeness of Surge-Response at sensitive locations</td><td>>10%</td><td>Requires professional judgment.</td><td>Yes</td></tr>
<tr><td>8. Surge-Response function—depends on interpolation method</td><td>>5%</td><td>Residual error between function and actual OS results.</td><td>Yes</td></tr>
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Issue 9

- Issue 9—hurricane sampling—discussed Part III.
- σ estimated using EVF fit to JPM surge hazard curves.
- About 10% ; 8% for East-Bank.
- ***Only uncertainty formally assessed in FIS***.
- But needs to be treated much differently for local residual risk management.
- Reasonably conservative estimate 2X based on:
  - Sampling uncertainty associated with Grand Isle tide gauge record;
  - Reconsidering record length represented by storms employed in estimating the joint probabilities.
- FIS hurricane sampling was pre-Isaac; underplays contribution of slow-moving, less powerful storms to overall frequency of hurricanes capable of producing a 100-yr surge—***potential source of surge hazard underestimation bias***.

Issue 10

- Issue 10 considers whether period of observed hurricanes is representative of current hurricane climate.
- The SELA FIS incorporated an adjustment to hurricane joint probabilities based on an initial effort to account for cycles of GoM hurricane frequency in the observed record.
- Uncertainties associated with effort not addressed in FIS surge hazards but would be appropriate for local projects.

Factor	Potential Surge σ	Evaluation of σ	FIS SOPs	Localized Variation?	Local Residual Risk Reduction SOP
9. Hurricane sampling	>8%	Use regional hurricane history to develop joint probabilities. Fit EVF to the surge hazard curve.	Region-wide uniform σ included in surge CI	No	Depending on exposure, include slow-moving low intensity storms in the joint probabilities. Use a reasonably conservative approach to the selection of EVF type and assigned sample length; adjust using analysis of local tide gauge record.
10. Representativeness of historical hurricane record	>10%	Requires professional judgment.	Not currently addressed.	No	Adjust future surge hazard for trends; include a reasonably conservative factor in CI for climate cycle and trend uncertainty.

Surge Hazard Estimate Uncertainty

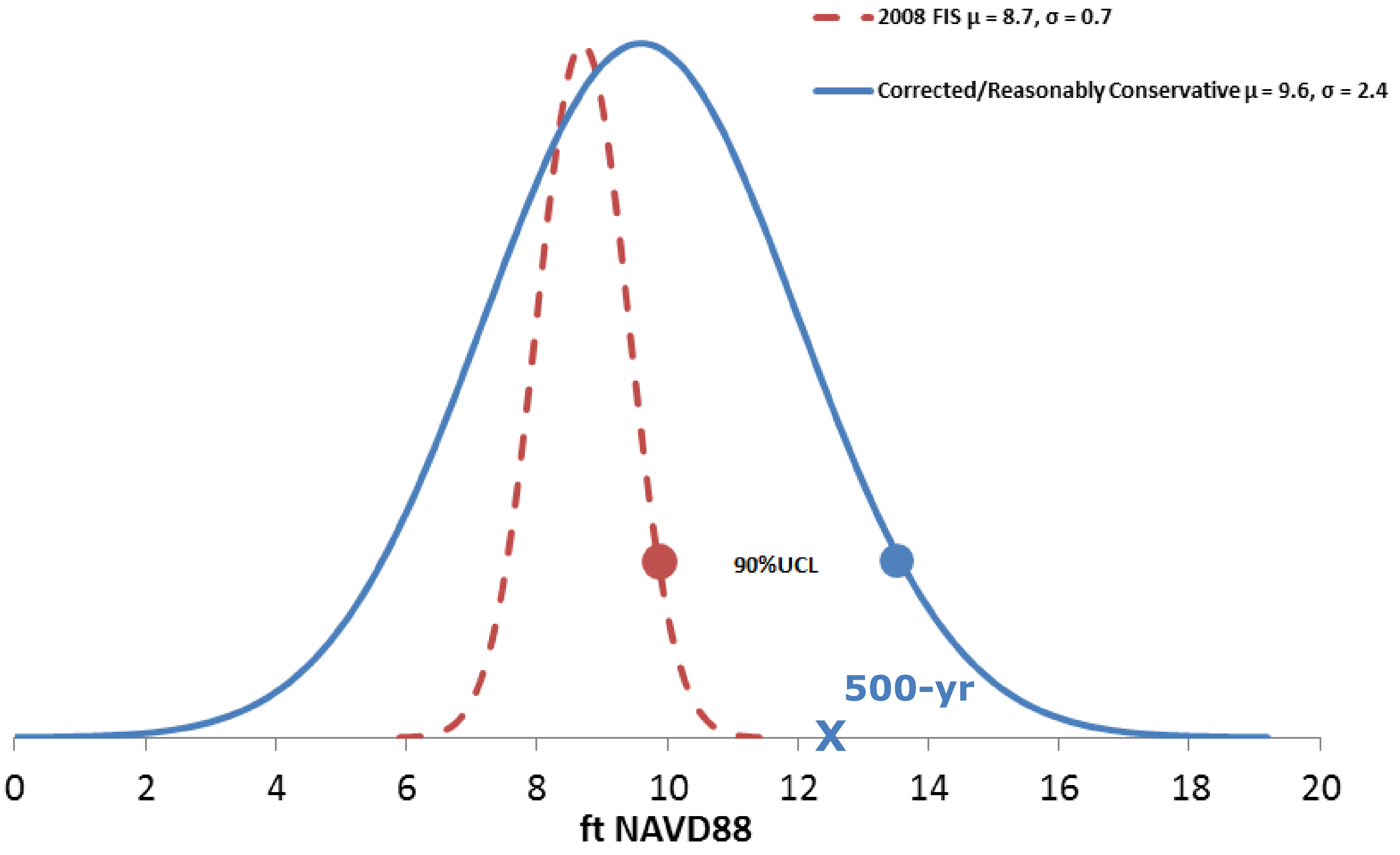
- FIS overall surge uncertainty only addresses Issue 9, and not conservatively.
- For the NO Lakefront :

	USACE Original	**Corrected FIS**	**Reasonable Conservative for Risk Management**
100-yr ft NAVD88	8.7	9.6	9.6
σ	0.7	0.8	2.4
1.645σ	1.2	1.3	3.9
90%UCL ft NAVD88	9.9	10.9	13.5

- As noted previously, the post-Katrina spread between FIS 100- & 500-yr surge estimates for the New Orleans Lakefront was 2.6 ft.

Thus, a reasonably conservative 90%UCL for the 100-yr surge is actually much higher than the base estimate for the 500-yr surge—an essential point for local surge residual risk management!

NO Lakefront 100-yr Surge Uncertainty



Surge Hazard Estimate Uncertainty

- If this reasonably conservative NO Lakefront 90%UCL seems high, recall the post-Katrina increases to the MRGO surge hazards.
- ***Bottom line: the FIS 100-yr surge could easily underestimate the true hazard (overestimate the true return period) by a factor of two.***
- Nominal 500-yr surge estimates are subject to even greater uncertainty than the 100-yr estimates.
- ***Hurricane Katrina's surge could thus be conservatively regarded as closer to a 200-yr event than the 400-yr event indicated by the FIS analysis.***

Independent Exposure

- Independent exposures are separate hazard events.
- A polder or region with multiple independent surge hazard exposures is subject to a multiple of the surge hazard.
- The actual multiples for polder & regional 100- & 500-yr events in the New Orleans area have not been defined.

Local Hazard	***Polder Hazard (Example of Two Independent Exposures)***	**Regional Hazard (Example of Five Independent Exposures)**	**Future Regional Hazard (Local Hazard X2)**
100	50	20	10
500	250	100	50
1,000	500	200	100

Over a 10-yr timeframe, local 100- and Nominal 500-yr events have 39.5 and 9.5% regional probabilities. If the local surge hazard is increased by a factor of two, a local Nominal 500-yr surge event has an 18.1% regional probability.

Future Reduction of Surge Hazard Uncertainties

- ***Aleatory*** uncertainties: inherent & irreducible randomness in the natural phenomena
  - Issues 2, 3, & 5 — Aleatory.
  - Research on 5 (pre-storm setup & rainfall) should allow it to be added in future FISs.
  - Appropriate for epsilon—incorporate into hazard estimate.
- ***Epistemic*** uncertainties: depend on the state of knowledge; potentially reducible in the future with further improvements to observations, analysis, & modeling.
  - Issues 1, 4, 6, 7, 8, 9 & 10 — Largely Epistemic.
  - Should be used to construct UCLs.
  - UCLs are lower if uncertainties are included in epsilon.
  - Issues 1, 4, 6, 7 & 8: research & continued improvements in HPC/High-Resolution & JPMs may be able to substantially reduce.
  - Issues 9 & 10: many more decades of hurricane observations will be necessary to reduce.

Revising Surge Hazard Analysis

- Managers of surge risks beyond NFIP have increasingly recognized surge hazards must be regularly reanalyzed.
- However, institutionalizing periodic surge hazard reanalysis requires major investments in scientific research, data collection, HPC, & administrative functions.
- In meantime, for residual risk management purposes
  - Correct 100- & 500-yr surge estimates for FORTRAN errors & likely local bias issues.
  - Use reasonably conservative surge uncertainty to better assess UCLs.