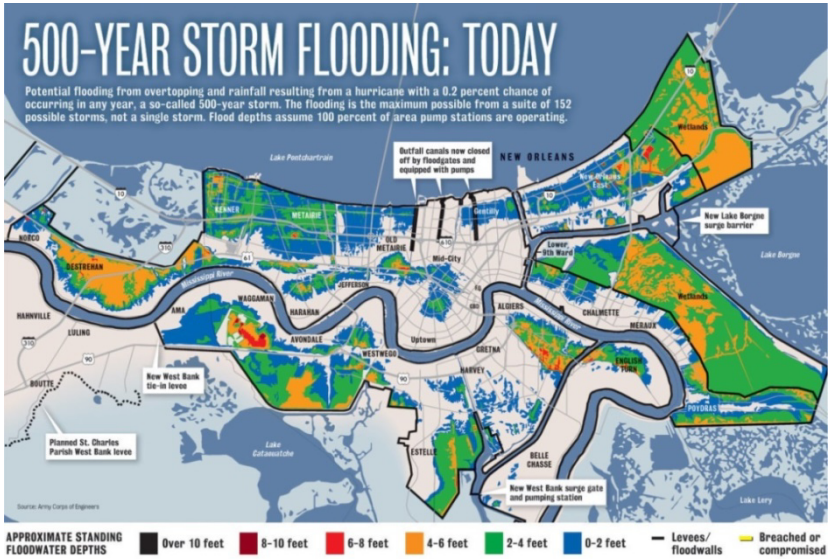
New Orleans
Hurricane Surge Risk Management

Part V. Post-Katrina Surge Risk Management



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June 2015

Part V. Topics

- HSDRRS: NFIP-Based Design
- Surge Residual Risk Evaluations
- 10 Developments in Surge Residual Risk Reduction
- General Limitation
- 8 HSDRRS Technical Issues
- Political Support & Funding Challenges
- Fragmentation of Responsibilities

HSDRRS: NFIP-Based Design

- Congress authorized/funded accelerated repair/completion of NO regional levees.
- Authorization redirected USACE to NFIP 100-yr surge hazard.
- Re-establishing NFIP levees was a pressing step toward revitalizing the City's property values & economy.
- NFIP objective quicker/easier/cheaper than more extreme storm.
- USACE emphasized this ***pivot*** with an explicit re-designation of the project as a "**Hurricane & Storm *Damage Risk Reduction System***," eliminating reference to "Protection."

BUT, Post-Katrina design along NO Lakefront for a 100-yr surge (USACE uncorrected) is for a surge event more than 2 ft below the previous SPH-surge protection objective, and more than 3 ft below Katrina's actual surge.

1st Time Levee is Designed Below Surge of Record!

HSDRRS: NFIP-Based Design

- The NFIP requires that coastal levees have 2 ft freeboard; but also high enough to prevent **wave** overtopping & erosion during 100-yr surge.
- NFIP ***Elevation FOS*** for wave overtopping***:***
  - Above 0.1% wave run-up; or
  - Statistical treatment of 100-yr overtopping uncertainty—minimize chance of erosion breaching as well as overflow volume.
- USACE approach for HSDRRS:
  - Height must ensure that 100-yr overtopping at a 90% non-exceedance level (q90, 80%UCL) is below 0.1 cfs/ft.
  - Also that q50 is below 0.01 cfs.

Monte Carlo Analysis of q90

- Empirical overtopping equations:
  - Standard weir free overflow.
  - Van der Meer levee wave overtopping.
  - q is a function of

    Freeboard (crown minus surge) Wave height & period

    Embankment geometry Empirical loss coefficient
- Variation for the 100-yr surge, wave height & period, and the loss coefficient determined by respective uncertainty distributions (σ values).
- Equation solved 10,000 times with each solution using randomly drawn values for inputs.
- Set of results provides uncertainty distribution for q; q90.

HSDRRS: NFIP-Based Design

HSDRRS design increased the crown elevation by:

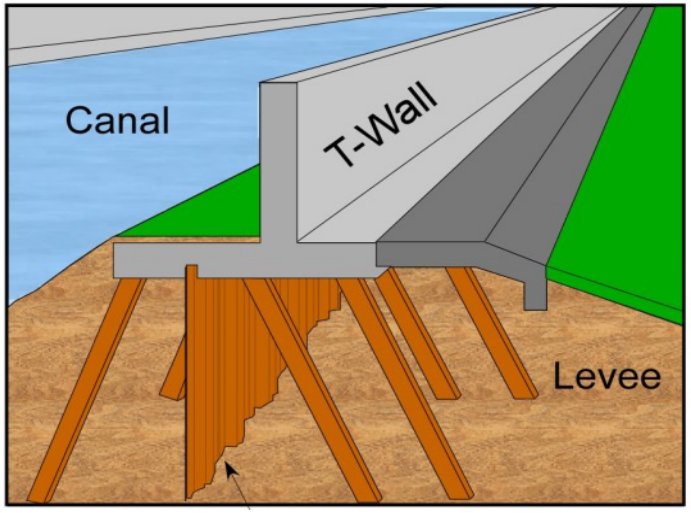
- 0.5 ft at NO Lakefront.
- 9.6 ft at MRGO location (with the IHNC Barrier).

As-built crowns may be higher depending on geometry, overbuild & other construction considerations.

	NO Lakefront		**MRGO (Bayou Dupre)**			
			W/O IHNC Barrier		**W/ IHNC Barrier**	
SPH High-Level Design	16.0 ft MSL	4.5 ft above SPH 15.0 ft above LML	17.5 ft MSL	4.5 ft above SPH 16.6 ft above LML		
HSDRRS Design (w/o RSLR)	16.0 ft NAVD88	6.4 ft above 100-yr 15.5 ft above LML			26.5 ft NAVD88	8.9 ft above 100-yr 26.2 ft above LML

HSDDRS Design/Construction

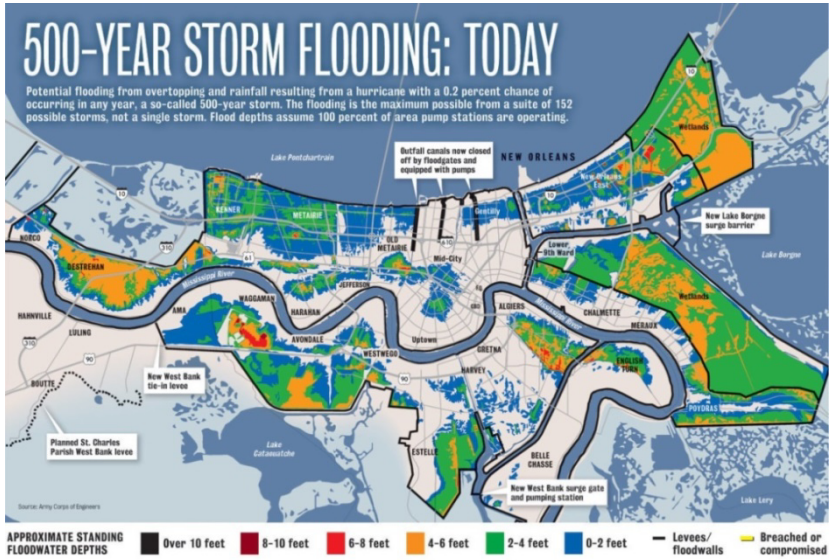
- Several major geotechnical improvements over the previous SPH project:
  - Batter pile-supported "T-" and "L-" designs for floodwalls.
  - East-Bank batter-pile supported walls employed along more than 20% of 111 mile system, including new 1.8-mile IHNC Barrier across the Funnel.
  - More rigorous levee material and construction requirements.
  - Adoption of accurate GPS-based vertical control methods.
- HSDRRS construction essentially completed in 2013.
- Cost approaching $14 billion.
- Received NFIP accreditation in February 2014.



Surge Residual Risk Evaluations

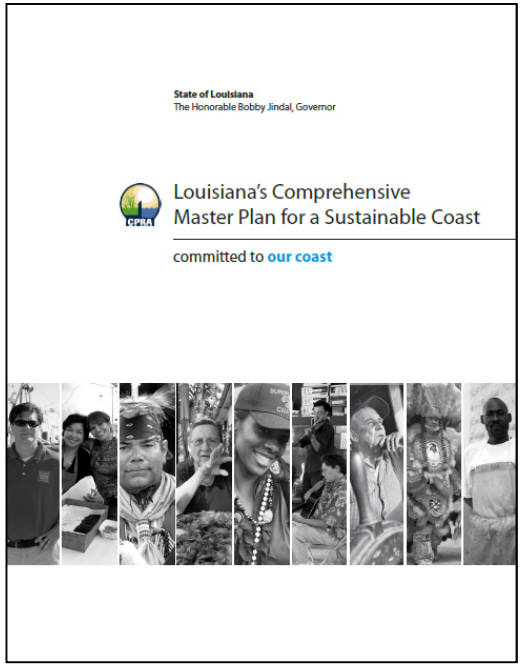
- Polder surge risks beyond the NFIP 100-yr level.
- USACE (for IPET, 2009) an initial attempt at quantifying residual polder inundation hazard.
  - HPC modeling of an FIS storm subset.
  - Innovative JPM-OS.
  - Additional factors related to interior flood levels:

Overtopping Breaching Rainfall Interior routing Drainage/pumping



Residual Risk Reduction Evaluations

- 2009 USACE LaCPR Report authorized by Congress to evaluate options for further federal action in reducing residual risks.
  - Investigated higher levees & other alternatives.
  - Employed results of the FIS hazard analysis, plus additional HPC/High-Resolution surge modeling for various alternatives.
- LA CPRA Master Plan (2007 & 2012)
- CBDG/SLFPA-E funded Bob Jacobsen Study (2015)
- 10 developments in surge residual risk reduction.


State of Louisiana
The Honorable Bobby Jindal, Governor

Louisiana's Comprehensive
Master Plan for a Sustainable Coast

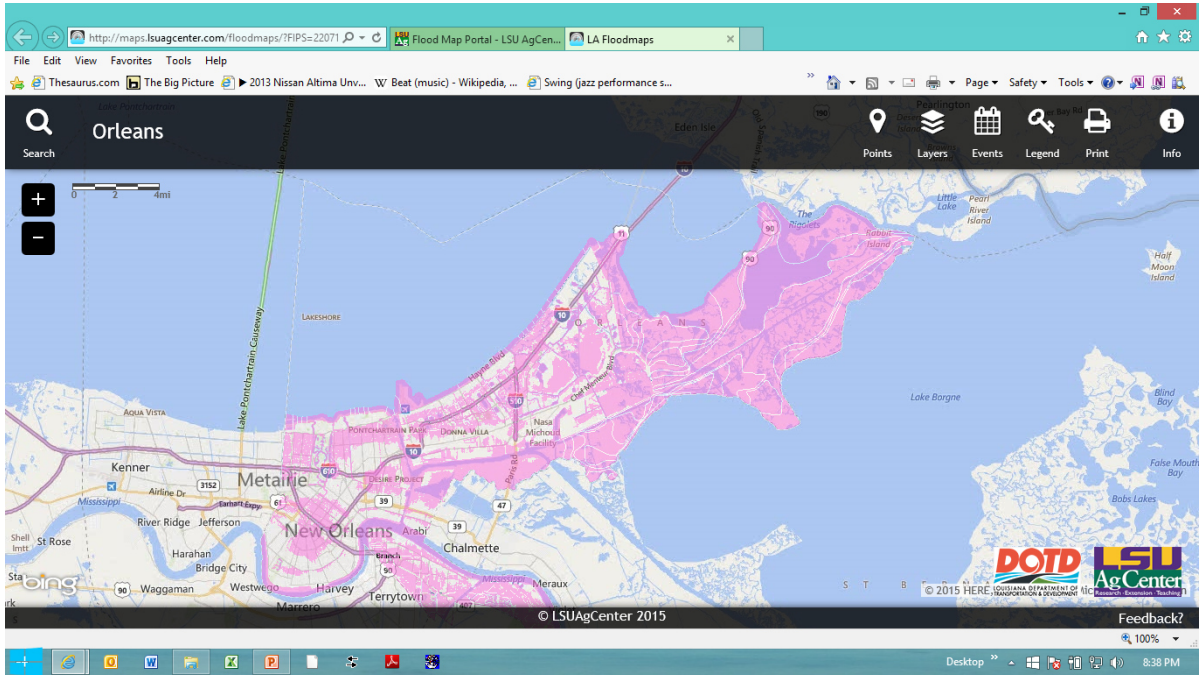
committed to our coast

10 Developments in Surge Residual Risk Reduction

1. **Evacuation.**
   - Clearly acknowledged surge hazard limits for the HSDRRS.
   - Federal, state, & local hurricane response agencies continued to refine plans for mandatory evacuation.
     - Adjusting the ContraFlow
     - Modifying evacuee sheltering arrangements
     - Addressing individuals with health, financial, and logistical hardships.
   - Hurricane/surge forecasting advances continue to confidence in mandatory evacuation notices.
   - August 2008 mandatory evacuation of the City during Hurricane Gustav highlighted ongoing progress in the City's evacuation; **BUT** more needed (see Wolshon 2006 & Campanella et al 2012).

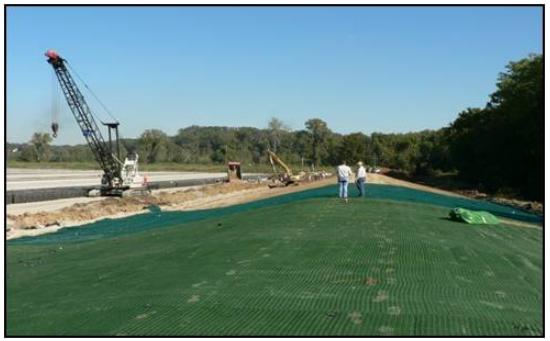
10 Developments in Surge Residual Risk Reduction

2. **Flood insurance.**
   - Local Congressional representatives have worked to
     - Expand the USACE SELA program to further reduce interior 100-yr flood hazard zones, thereby reducing premiums for more polder properties.
     - Ensure NFIP premiums for hazard zones remain affordable.



10 Developments in Surge Residual Risk Reduction

3. **HSDRRS floodwall & levee resiliency—<u>CRITICAL</u>!**
   - Overtopping alone >100-yr surge (even >500-yr) *not catastrophic; <100-yr rainfall volume;* (1000s acre-ft)
   - Congress authorized/funded HSDRRS resiliency to lessen risks of ***catastrophic breaching*** during >100-yr events.
     - USACE design: all features to ***withstand collapse breaching from the Nominal 500-yr surge***.
     - Floodwall overtopping resiliency: heights for 2057 100-yr
     - Levee overtopping resiliency: armoring to protect levees from 500-yr overflow.
     - 500-yr q90 employed as ***Armoring FOS***.
     - USACE conducted large-scale physical experiments on wave-induced turf erosion & pilot projects to evaluate high performance turf reinforcement mat (HPTRM).



   - Risks remains for breaching at more extreme storms.

10 Developments in Surge Residual Risk Reduction

4. **HSDRRS upgrade.**

2012 REPORT CARD FOR LOUISIANA'S INFRASTRUCTURE

100-YEAR FLOOD PROTECTION NOT WHAT MOST PEOPLE THINK

The 1% annual chance of exceedance, or 100-year level of flood protection, does not imply that a flood would occur once in 100 years as some people believe. In actuality, a 100-year level of flood protection means there is a 26% chance of flooding during the 30 year life of a typical mortgage. By contrast, a 200-year level of protection corresponds to a 14% chance of flooding over a 30-year period. A 500-year level of protection, which many have advocated as a more appropriate standard, results in about a 6% chance of flooding over a 30-year period.

Although many believe a 100-year system does not adequately reduce potential flood damages in large urban areas, the report card grades are based on that standard. This is consistent with the current levee system evaluation for the NFIP and current design practice in the U.S. We agree that a 100-year system does not adequately reduce potential flood damage and risks to the public in large urban areas. If higher standards of protection were in place, the grades would be lower.

The flood protection systems in Louisiana, including the control structures that facilitate the management of the Mississippi River water levels near the highly populated cities in south Louisiana, are some of the best, most robust systems in the world. This was demonstrated in the spring of 2011, when for several weeks, record high water levels on the Mississippi River tested the levees. In spite of the highest historic recorded water elevations ever recorded at Vicksburg, Natchez and Red River landings, the MRT project levees performed as designed. The Morganza spillway, which is designed to relieve flows from the Mississippi River by redirecting water to the Atchafalaya River basin, was successfully operated for only the second time since its construction. This historic event exceeded the 100-year high water on the Mississippi River at most Louisiana gauge locations upstream of Baton Rouge. While the levees performed as designed, in some parts of Louisiana, there was not enough freeboard to prevent overtopping of the levees from boat wakes. As a result, flood-fighting efforts used Hesco baskets and sandbags on the levee crown to retain more water. These outstanding levee systems and flood-fighting efforts prevented an estimated $68 billion in damages in the New Orleans district alone.

FACTS AND ISSUES

Criteria for judging levee systems in Louisiana included assigning grades based on the following categories:

- *Capacity* The level of protection afforded relative to a 100-year flood event.
- *Condition* Based on regular USACE inspections, the levees are judged as Acceptable (A), Minimally Acceptable (M), or Unacceptable (U).
- *Funding* Assessments of the necessary evaluations and urgency for upgrades within a system and the availability of the funds required.
- *Operation & Maintenance* Availability of adequate funds, equipment and personnel needed to perform O&M requirements.
- *Public Safety* Ability of the flood protection systems to meet or exceed the 100 year flood protection level under current design standards.
- *Resilience* The ability of the flood protection system to withstand overtopping without excessive scour and erosion.

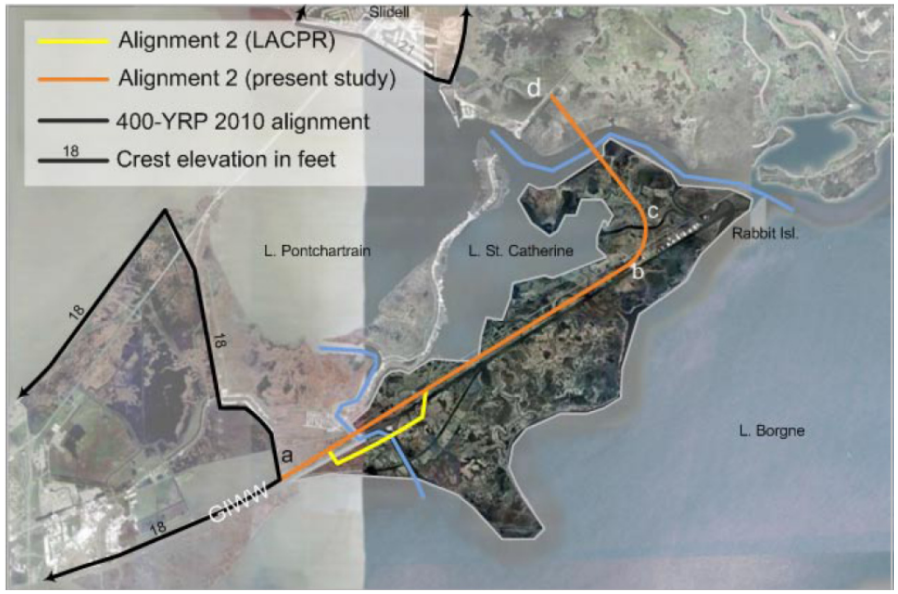
CAPACITY Based on our evaluations, the capacity of the levee systems varied significantly throughout the state. In general, the systems in the greater New Orleans area graded the highest and were the only levee systems in the state to receive an A in this category. Capacity grades for systems elsewhere in the state ranged from B to F. A grade of C and below indicates the system does not provide protection from a 100-year event. Slightly more than half of the levee systems in Louisiana do not meet the 100-year elevation. Overall the average capacity of the flood control systems in Louisiana was graded a D+.

Levee systems provide flood protection by incorporating levees and associated structures such as flood walls, flood gates, control structures, surge barriers and

- LaCPR Report investigated options for upgrading the HSDRRS to a more extreme hazard levels—including up to a 1,000-yr level.
- Suggested that even upgrading the HSDRRS to meet Katrina's surge of record was not cost-effective given other options.
- CPRA 2013 Master Plan & ASCE Louisiana 2012 Report Card both recommended higher levee designs for NO.
- As of today, no detailed investigation of HSDRRS upgrade has been initiated.

10 Developments in Surge Residual Risk Reduction

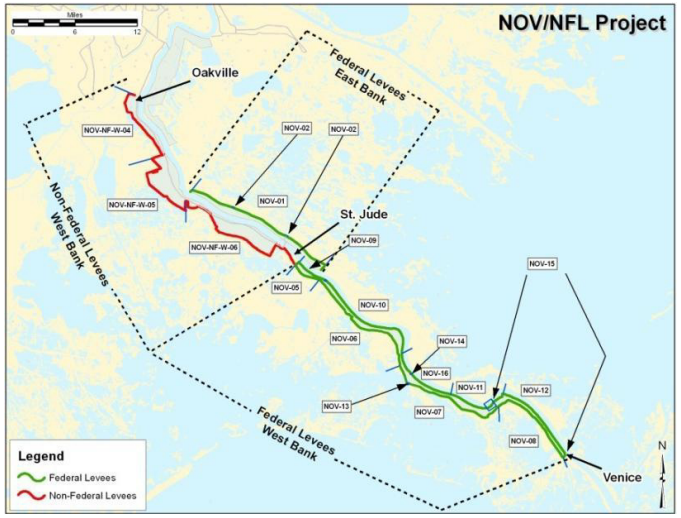
5. **The Lake Pontchartrain Barrier Plan.**
   - LaCPR Study & SLFPA-E (Ben C. Gerwick 2012) revisited the original Barrier Plan (see Part I).
   - Both showed that it reduces Lake surge hazard less than previously estimated
   - Does not prevent "tilting."
   - Aggravates surge hazards in surrounding areas.
   - At this time no further investigation of the Lake Pontchartrain Barrier Plan has been initiated.



NO-East Land Bridge Study, Gerwick 2012

10 Post-Katrina Developments in Residual Risk Reduction:

6. **Removal of Mississippi River levees.**
   - LaCPR Study investigated the effect of taking down some levees in Plaquemines Parish.
   - Some reduction of East-Bank surge hazard.
   - Also potentially facilitates restoration of wetlands in the lower delta.
   - At this time no further investigation of removing downriver levees has been initiated.



nola.com 2012

10 Post-Katrina Developments in Residual Risk Reduction:

7. **Coastal protection and restoration projects.**
   - LaCPR Study and CPRA Master Planning process, as well as local agencies, have identified numerous basin and sub-basin scale projects:

Barrier Islands Ridges/Cheniers Marsh Forests Close Canals

   - Many promoted as means to reduce surge.
   - One cost-effective measure to complement the HSDRRS would likely be restoration/ maintenance of band of resilient coastal forests fronting the system to reduce wave heights.

10 Developments in Surge Residual Risk Reduction

8. **Polder interior compartmentalization.**
   - 2015 SLFPA-E report reviews numerous topographic natural & man-made features in each polder.
   - Recommended 3 alternatives:
     - Improvements to East Jeff/St. Charles Parish Line barrier.
     - Upgrade of remaining IHNC Basin I-walls.
     - Use of Central Wetlands to reduce surge levels in IHNC Basin.
   - Further engineering evaluation of feasibility, followed by securing funding for final design & construction.

10 Developments in Surge Residual Risk Reduction

9. **Interior drainage.**
   - Interior drainage reduces risks associated with low to moderate overtopping volumes:

     10,000 cfs = 20,000 acre-ft/day
   - Post-Katrina, USACE has continued to implement drainage improvements under SELA.
   - No improvements specifically addressing surge risk reduction have been studied.

10 Developments in Surge Residual Risk Reduction

10. **Flood-proofing.**
    - Various post-Katrina studies & plans have recommended further development of "Non-Structural Alternatives" for surge risk reduction, including:
    - More stringent ordinances & building codes; greater
        - Elevation of residential, commercial, and public buildings.
        - Flood-proofing of critical electric, gas, communication, water, & sewerage utilities & transportation components.
        - Flood-proofing of key community, historic, and cultural assets.

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Recall from Part I that flood-proofing is the earliest, most basic element of flood risk management.

General Limitation

Foremost, as history shows, all flood risk management is subject to the potential errors & uncertainties of the flood hazard estimate.

Thus, issues with FIS surge hazard estimates discussed in Part IV mean that surge risks to life and property are likely to be underestimated.

10 HSDRRS Technical Issues

1. ***Elevation FOS*—100-yr q90 estimates.**
   - Since 100-yr q90 estimates support NFIP accreditation, therefore ***only used an NFIP approach to surge uncertainty***.
   - ***From a local residual risk management perspective, HSDRRS 100-yr design has minimal Elevation FOS.***
   - Reminiscent of SPH-surge protection design.
   - Bob Jacobsen (March 2015) revised q90 (& q50) for:
     - Surge hazard correction for FORTRAN errors.
     - Surge uncertainty: USACE used only 1 of 10 elements; reasonably conservative value is 3X higher.
     - Conservative wave heights at inshore locations.
     - Correction of Monte Carlo code issues.

	Design Limit cfs/ft	**NO Lakefront NO01**	**MRGO (Bayou Dupre) SB13**
100-yr q50	0.01	0.03	0.01
100-yr q90	0.1	0.66	1.05

10 HSDRRS Technical Issues

2. ***Armoring FOS*—500-yr q90 estimates.**
   - 500-yr q50 & q90 affected by the same issues as 100-yr.
   - ***Revised estimates mean that the degree of risk reduction provided by selected armoring measures significantly less than anticipated.***
   - More rigorous armoring—i.e., stone or paving instead of HPTRM—could be appropriate to provide a greater 500-yr resiliency FOS.

	Design Limit cfs/ft	**NO Lakefront NO01**	**MRGO (Bayou Dupre) SB13**
500-yr q50	Pave if ≥2.7	0.96	4.86
500-yr q90	HPTRM or Pave if ≥4.0	10.69 cfs/ft	31.41 cfs/ft

10 HSDRRS Technical Issues

- Most vulnerable East-Bank locations due to low Elevation and Resiliency FOSs:
  A. St. Charles Parish levee (F = freeboard)

	Crest	100-yr				500-yr			
	NAVD88	q50	q90	F50	F90	q50	q90	F50	F90
SC02-A	15.5	0.22	5.55	3.4	-0.47	6.46	66.21	-0.1	-6.09
SC02-B	14	0.66	8.22	2.4	-1.31	8.83	79.37	-1.1	-6.9

based on corrected Monte Carlo analysis

B. IHNC Basin—500-yr barrier overflow + rainfall + pumping discharges into basin could raise water to levels threatening remaining I-Walls.

10 HSDRRS Technical Issues

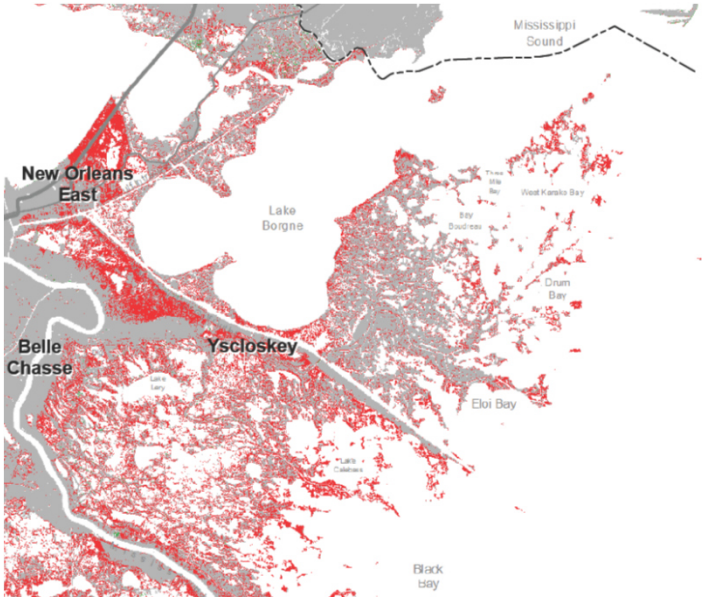
3. **Supplemental levee lifts.**
   - Will be required along most HSDRRS levee segments over the upcoming years to continue meeting the 2007 design elevation.
   - Consolidation & settlement rates are high for inland levee reaches built across former swamps.
   - Additional periodic lifts will be necessary to meet rising design elevation in accordance with the USACE's 2057 design elevation addressing future RSLR.
   - Levee lifts are not currently federally funded.
   - Vulnerable reaches could be exposed to even greater 100- & 500-yr overtopping if levee crowns fall below design elevation.

10 HSDRRS Technical Issues

4. **Armoring implementation.**
   - Installing armoring soon will result in future expensive removal during future lifting and reinstallation.
   - Deferring armoring exposes the system to breach risks but might be practical if the deferral is only for a short time.
   - The issue becomes more complex as the time horizon is extended to account for more consolidation, settlement, RSLR, and even revised 100-yr surge estimates.

10 HSDRRS Technical Issues

5. **Impact of coastal erosion & vegetation changes on 2057 surge.**
   - USACE assessment of RSLR on 2057 design elevations did not include additional future changes to surge height due to coastal erosion & vegetation change.



50-yr Land Loss Projection, CPRA 2012 Master Plan

10 HSDRRS Technical Issues

6. **Vertical control methodologies.**
   - GEOID model ellipsoid height measurements can still introduce errors on the order of several tenths of a foot.
7. **Remaining weaknesses in geotechnical support conditions.**

Legacy pipelines Localized voids Transmissive soils Slip planes

   - Weaknesses could still present opportunities for collapse breaching—especially for remaining I-wall segments.
   - More research is needed on techniques for investigation of weaknesses and characterization of collapse breach probabilities.
8. **Potential long-term structural design weaknesses.**
   - T-Wall pile corrosion.
   - Batter pile down-dragging (due to subsurface settlement/subsidence)
   - Flood-side armoring.

10 HSDRRS Technical Issues

9. **Operation of major channel gates & additional perimeter pump stations.**
   - Closure timing
   - Measures must be available to ensure that vessels & bank structures in interior channels do not break free & damage surrounding floodwalls.
   - Pre-established & well-rehearsed coordination with federal & private navigation interests.
   - Pumping at redundant perimeter stations must be coordinated with interior pump stations to ensure proper operating levels.

10 HSDRRS Technical Issues

10. **Maintenance (especially remote reaches).**
    - Keeping healthy grass cover on earthen embankments.
    - Controlling traffic on levee crowns.
    - Controlling nuisance animals which burrow & damage embankments.
    - Repairing crown and embankment damage & erosion.
    - Maintenance of enhanced turf & HPTRM for armoring resiliency.
    - Preventing & repairing corrosion of steel components.
    - Preventing & repairing significant cracks & other damage to concrete components.
    - Repairing and/or replacing worn or damaged mechanical items.
    - Ensuring the integrity of designed & designated wave breakwater structures (including railroad embankments along the NO East Lakefront).
    - Major repairs occurring after storm surge events, including lesser storms.

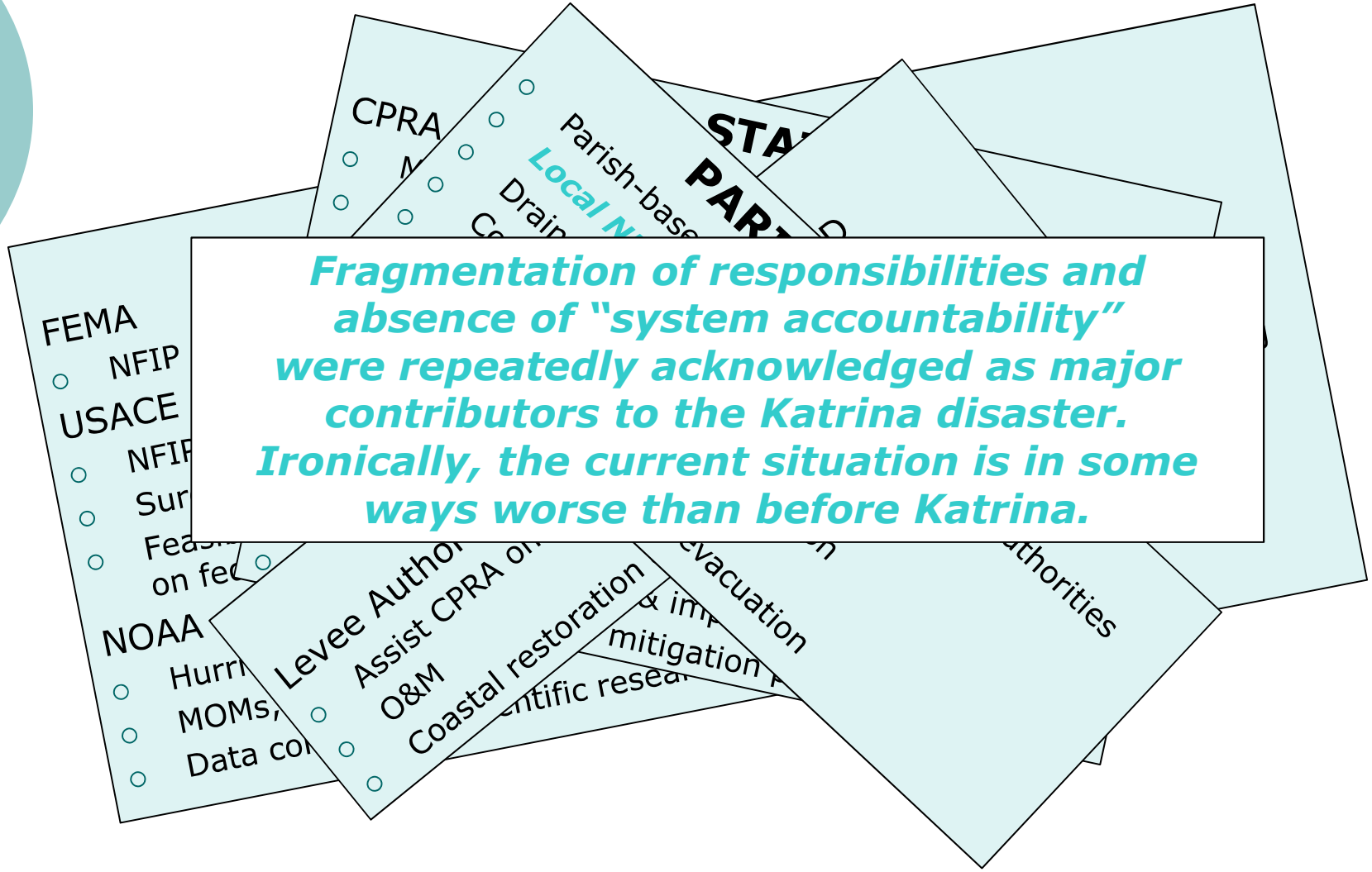
Coastal Protection & Restoration

- Major technical concern about effectiveness against extreme surge—deep submergence of landscape.
- Surge-Response needs extensive further scientific research.

Political Support/Funding Challenges

1. Voters of St. Bernard Parish have twice declined to pass a tax to increase funding for O&M of their HSDRRS reaches.
2. Underfunding of evacuation contingencies for those with health, logistical, or financial problems.
3. Coastal restoration plans must consider those whose ways of life are tied to the existing coastal landscape; ensure that short- & long-term impacts are reasonable given uncertainties about long-term project success.
4. Staunch private property interests oppose the establishment of incentives (much less mandates) to expand flood insurance participation & private coverage, as well as the imposition of greater flood-proofing requirements.

Fragmentation of Responsibilities



Fragmentation of responsibilities and absence of "system accountability" were repeatedly acknowledged as major contributors to the Katrina disaster. Ironically, the current situation is in some ways worse than before Katrina.

Fragmentation Affects . . .

1. **Design decisions involving tradeoff of construction costs/schedule versus long-term O & M costs/headaches.**
   - USACE—responsible for design/construction, 70% cost.
   - CPRA—co-sponsor for design/construction, 30% cost.
   - Local levee authorities—SLFPA-E, SLFPA-W, PLD, responsible for 100 percent of O&M.
   - Rush to rebuild after Katrina hampered detailed evaluation of "Right-Sizing" tradeoffs:
     - Rebuild on 40 Arpent & Maxent Levees.
     - Rebuild higher/stronger interior levees/T-Walls along IHNC & Outfall Canals instead of complex gates & redundant perimeter pump stations.
   - CPRA & Local Authority disagree with USACE decisions on coating of T-wall sheet piles & armoring for waves.

Fragmentation Affects . . .

2. **Rational risk reduction.**

   USACE (as part of DOD) narrowly construes Congressional authorizations. These interpretations do not always allow for cost-effective management of risk; such as situations in which raising levees is best approach for reducing risk.

3. **Formal HSDRRS NFIP re-evaluation & re-accreditation.**

   CPRA & local HSDRRS authorities—together with FEMA &USACE—will have to determine if a re-analysis of the surge hazard is required, as well as if treatment of surge uncertainty needs to be revisited. Some local authorities concerned with residual risk have shown understandable interest in a more rigorous restudy. Complicating a restudy is the fact that the CPRA and local HSDRRS managers are not the state/local NFIP agencies, some of which may be opposed to initiating FIS revision.

Fragmentation Affects . . .

4. **Coastal protection and restoration priorities.** 2013 SLFPA-E lawsuit against O&G operators as partly responsible for numerous coastal canals—to obtain compensation and restitution for impacts on regional surge. (The impact of the canals on extreme surges and the HSDRRS design and O&M is not settled.) The governor, CPRA, & other state coastal levee boards are opposed to the lawsuit on jurisdictional grounds and to way law-firm was contracted.