Hurricane Surge Hazard Analysis for Southeast Louisiana

SLFPA-E Coastal Advisory Committee and Invitees
February 21, 2013

Presented by
Bob Jacobsen PE, LLC
Consulting Coastal Hydrologist
Objective

○ Review state-of-the-practice in surge hazard analysis; rapid advances over last several years
  ● Ongoing coastal FIS in many states (TX, NC, SC, GA, FL-Atl, FL-GoM, AL)
  ● Academic research
  ● Work by USACE ERDC and NOD.

○ Evaluate 2005-09 analysis by USACE for FIS/IPET/CPR/HSDRRS

○ Recommend a future improved analysis

“Hindsight is 20-20!”
Organization—Five Parts

- Part I. Hurricane Climatology Draft Submitted
- Part II. Modeling Surge Physics Draft Submitted
- Part III. Hurricane Surge Hazard Analysis Draft Submitted
- Part IV. Hurricane Surge Hazard Analysis for Polders Draft Submitted
- Part V. Hurricane Surge Hazard Analysis for Future Conditions In Progress
Part I. Hurricane Climatology

Section 1. Hurricane Characteristics
1.1. Core Intensity
1.2. Core Size
1.3. Wind Field Geometry
1.4. Hurricane Dynamics
1.5. Track and Forward Speed

Section 2. The Influence of Seasonal and Climatic Trends
2.1. Seasonal Trends
2.2. Climate Cycles
2.3. Climate Change

Section 3. Hurricane Landfall Probabilities
3.1. Return Frequency for Landfall Intensity
3.2. Landfall Characteristics
3.3. Landfall Climatic Trends

Section 4. Hurricane Joint Probability Analysis
4.1. Overview of Hurricane JPA
4.2. Recent Hurricane JPA
4.3. Recent Application to Coastal Wind Hazard Studies

Part I. Conclusions and Recommendations
Part I. References
Part I. Attachments
Part I. Hurricane Climatology

- Loop Current and associated eddies cause SELA landfalling hurricanes to be more intense.
- Applying 1952-2011 hurricane record indicates slightly higher return frequencies than previously estimated by Resio.
- Recent research is highlighting importance of variation in CPD:$V_{\text{max}}$ (e.g., Hurricane Katrina), Holland B/IKE, decay, etc.
Part I. Hurricane Climatology

- Large, slow moving, lower intensity storms can contribute to 100-yr surge hazard.
- **USACE analysis does not account for contribution of storms with CPD > 955 mb.**

Hurricane Isaac
Part II. Modeling Hurricane Surge Physics

Subpart A. Hurricane Surge Physics

Section 5. Surge Components and Dynamics
5.1. Surge Components
5.2. Surge Dynamics

Section 6. Surge Physics
6.1. Surge SWL Physics
6.2. Wave Physics

Section 7. Surge and Coastal Landscape Interactions
7.1. Features Influencing Wind Setup
7.2. Features Influencing Conveyance
7.3. Features Influencing Wave Processes
7.4. Impact of Coastal Features Relative to the Surge Conditions

Section 8. Impact of Coastal Subsidence, Erosion and Climate Change on Surge

Subpart B. Hurricane Surge Modeling

Section 9. SWL Modeling
9.1. General Background
9.2. Model Numerical Methods
9.3. Node Attribute Data
9.4. Instability Issues
9.5. Model Performance Testing

Section 10. Wave Modeling
10.1. Open Ocean and Nearshore Waves
10.2. Interior Waves
10.3. Coupling of 2D SWL and Wave Models

Section 11. ADCIRC Surge Modeling
11.1. ADCIRC Code
11.2. ADCIRC SWL and Wave Coupling
11.3. ADCIRC Mesh Development
11.4. Influence of Key ADCIRC Parameters and Mesh Resolution
11.5. Project Considerations

Section 12. Recent Applications of Hurricane Surge Modeling
12.1. Overview of Post-2005 Surge Models
12.2. USACE 2006 Louisiana Surge Model
12.3. Other FIS Surge Models
12.4. Other Applications

Part II. Conclusions and Recommendations
Part II. References
Part II. Modeling Hurricane Surge Physics

- Fitzpatrick et al (2010) have shown that the combination of \((\text{IKE}^{1/2} \times V_{\text{max}})\) and shelf bathymetry is an excellent predictor of simplified, generic regional surge height.
Part II. Modeling Hurricane Surge Physics

- But for complex deltaic coasts, local conveyance features exert significant influence; surge routing is sensitive to variations in
  
  Flow length  \( \text{Depth}^{4/3} \)  Manning’s \( n^2 \)

- Five important categories of conveyance features are
  
  Flood protection/hydraulic structures  Natural topographic features
  Other man-made embankments  Land cover
  Preferential conveyance pathways
Part II. Modeling Hurricane Surge Physics

- Impact of features on surge depends on
  - Surge stage—submergence of embankments, land cover, and channels reduces their importance in controlling conveyance and wave breaking relative to the surrounding landscape.
  - Areal size and continuity—long embankments provide much greater surge diversion and wider forest bands provide greater frictional resistance.
  - Erodability—barrier islands and other raised features that disappear quickly as surge rises will exert less influence; armoring can enhance the strength of raised features.

Low Surge Stage

Cross Section of Coastal Landscape

High Surge Stage
Part II. Modeling Hurricane Surge Physics

- 2006 ADCIRC-STWAVE FIS surge model was groundbreaking in scope at the time.
- However, many of 2006 technical approaches to mesh development, mesh elevation assignment, surge/wave code/model settings, parameters, etc have been superceded over last several years.
Part II. Modeling Hurricane Surge Physics

- 2006 ADCIRC-STWAVE FIS surge model was groundbreaking in scope at the time.

- However, many of 2006 technical approaches to mesh development, mesh elevation assignment, surge/wave code/model settings, parameters, etc have been superceded over last several years.

- **Reviews have shown significant evidence of local bias.**

- Model validation for Hurricane Katrina showed significant bias on south shore of Lake Pontchartrain.
Part III. Hurricane Surge Hazard Analysis

Section 13. Analysis of Surge Records
  13.1 Analysis of Tide Gauge and HWM Data
  13.2 Recent Evaluations of Tide Gauge Data
  13.3 Recent Evaluations of HWM Data
  13.4 Analysis of Wave Data

Section 14. Surge JPA
  14.1 Overview of Surge JPA
  14.2 JPM-OS
  14.3 Surge Response-OS
  14.4 Landfall Spacing
  14.5 Bias and Uncertainty in Surge JPA
  14.6 Preparation of Return Frequency Curves
  14.7 Wave Hazard

Section 15. Recent Applications of Surge JPA
  15.1 Southeast Louisiana FIS
  15.2 IPET Study
  15.3 Southwest Louisiana FIS
  15.4 2012 Louisiana Master Plan
  15.5 Mississippi FIS
  15.6 Other FISs

Part III. Conclusions and Recommendations
Part III. References
Part III. Attachments
Part III. Hurricane Surge Hazard Analysis

- Distinguish between the Surge Response-OS approach (Resio) and the JPM-OS approach (Toro)
- Surge Response-OS adopted to address problem of limited HPPC resources—provided a rationale for only 152 storms.
- Critical assumption: smooth response—but not applicable to complex coastline with sheltered water bodies.
- Now HPPC resources much less constraining. Recent FISs using hundreds of storms.
Surge Response OS

- 5 primary landfall locations for the central tracks
- 4 each for the southeast and southwest tracks
- Landfall spacing at about 1° longitude, or 30 mi.
- Intermediate (secondary) landfalls spaced at 15 mi
- Half the storm landfalls within a 1° (60 mi) segment south of New Orleans.
<table>
<thead>
<tr>
<th>GoM-CP [miles]</th>
<th>GoM-R [mph]</th>
<th>Landfall [mph]</th>
<th>0° direction froma</th>
<th>Track-Setb, (Number)c</th>
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<td>40.9</td>
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<td>SE</td>
<td>P (4)</td>
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<td>P (5)</td>
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<td>17.1</td>
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<td>6.9</td>
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<td>Central</td>
<td>P (5)</td>
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<tr>
<td>3-CP</td>
<td>15 CP-R</td>
<td>19 CP-R</td>
<td>30 CPD-R</td>
<td>152 Storms</td>
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</table>

P-Primary Track Set; S-Secondary Track Set (Landfall located between Primary Tracks)
Surge hazard curves (CDFs) were shifted from median estimate to provide some margin for uncertainty. At one location this increased the estimated 100- and 500-yr surges by 0.4 and 1.1 ft.
Part III. Hurricane Surge Hazard Analysis

Total epistemic uncertainty:
2.1 to 3.6 ft
+ 0.1 to 0.2*SWL

For SWL = 10 ft:
σ = 2.3 to 4.1 ft
90% CI = ±3.8 to 6.8 ft

Does not include all epistemic and aleatory uncertainties, some of which are non-normally distributed.
Part IV. Hurricane Surge Hazard Analysis for Polders

Section 16. Additional Hydrologic and Hydraulic Analysis
- 16.1 Perimeter Surge and Wave Conditions
- 16.2 Seepage
- 16.3 Overtopping
- 16.4 Breaching
- 16.5 Rainfall Accumulation
- 16.6 Drainage Pumping
- 16.7 Internal Routing
- 16.8 Interior Wind Setup and Waves

Section 17. Polder Inundation JPA
- 17.1 Polder Inundation Hazards
- 17.2 Overview of Hurricane Surge Polder Inundation JPA
- 17.3 JPM Set of Perimeter Surge Events
- 17.4 SOBRP Probability Scenarios
- 17.5 Preparation of Return Frequency Curves
- 17.6 Interior Wave Hazard

Section 18. Recent Applications of Polder Hazard Analysis
- 18.1 IPFT Risk and Reliability Analysis
- 18.2 USACE Louisiana CPR Study
- 18.3 USACE HSDRRS 100-yr Design
- 18.4 USACE HSDRRS Resiliency Design

Part IV. Conclusions and Recommendation

Part IV. References

Part IV. Attachments
Additional H&H: Perimeter Surge & Waves

- Surge model doesn’t always provide hydrograph—need to artificially construct.
- Also need foreshore waves.
- Questions remain on foreshore wave field distribution.
- Breaker parameter \( (H_s/\text{Depth}) \): 0.4 – 0.7, but insufficient data

**Figure 16.2. Transformation of Waves Approaching a Perimeter Barrier**
(Not to scale)
Additional H&H: Seepage

London Avenue Canal Breach
IPET

Also can have man-made pathways—need inventory!
Additional H&H: Overtopping

- **Phase 1**: Crests Below Crown—Runup Only
- **Phase 2**: Crests Above Crown
- **Phase 3**: Zero Freeboard
- **Phase 4**: Troughs Above Crown, Free Flow with Notable Pulses

**Average Overtopping**

**Phase 5**: Free Flow Dominates

**High Peak Velocities with Pulses!**
Additional H&H: Breaching

- **Erosion**
  - Exterior side from currents and waves, especially non-cohesive soils (hydraulic fill).
  - Interior side from overtopping, especially at > 1cfs/ft

- **Collapse**
  - Movement of structural members (above or below ground) and/or support of underlying and adjacent ground.
  - Due to excess loads, loss of soil mass (excavations, erosion, seepage-scour, seepage-boils)

- **Failure Rules describe**
  - Breach invert and length (I-L)
  - That would result at reach due to the various location-specific factors in combination with the time varying exterior SWL.
    - a. Type—levee, I-wall, T-wall, gate, levee-floodwall transition, etc.;
    - b. Critical Design Features—elevation, embankment soil type (e.g., clay versus hydraulic fill), slopes, pile depths, etc.; and
    - c. Reach Geology—depth and permeability of seepage zones; depth, density, and cohesive strength of overlying soils; presence of seepage pathways; etc.
Additional H&H: Breaching

- Failure rules—more
  - Include a series of “steps”—e.g., changing I-L with increasing $-R_c$; simple failure rule is a single step.
  - Can be written to account for uncertainty in each step.
  - Probability of a particular I-L step can vary from to 1 as the negative freeboard worsens beyond the step threshold.
  - Sum of all probabilities, including the no failure condition for each step must equal 1 for each storm.
  - Fragility curve depicts relationship between failure probability and $-R_c$.
  - Fragility curves can incorporate wave conditions and interior SWL.
Additional H&H: Rainfall

- No published correlations or measures of scatter for precipitation as a function of hurricane characteristics
- Some relationship to side of storm and distance
- Significant threats from storm bands and “training.”
Additional H&H: Pumping

- Components
  - Local gravity collection systems
  - The major gravity channel network
  - Local lift stations
  - Perimeter pump stations

The various components of the interior forced drainage systems typically have limited design capacities.

During polder inundation, pump stations may be subject to outages due to:
  - Loss of power;
  - Submergence of components;
  - Shutdowns or start-up failures by automated control systems
  - Absence of manual control

- No published probabilities for pump performance during surge inundation—generally assume some capacity %
Additional H&H Analysis: Internal Routing

- Address the local, time-varying SOBRP occurring around and within the polder, as well as internal conditions:
  - Detailed interior
  - Major internal gravity drainage features
  - Natural and man-made internal barriers
  - Major openings in the internal barriers
- 2D—e.g., ADCIRC
- 1D—level-pool, basic stage-storage; sub-basins
- Need to couple internal routing with
  - SOBRP process program (Excel, Matlab, Fortran)
  - Perimeter surge hydrographs and local waves.
  - Tight coupling not available
Additional H&H : Interior Wind and Waves

- Steady-state wind setup is given from a balance of the wind stress and hydrostatic forces (ignoring bottom friction and other forces):

\[ h = C_{D_{\text{air-water}}} \frac{\rho_{\text{air}}}{\rho_{\text{water}}} \frac{LU^2}{gd} \text{ with } C_{D_{\text{air-water}}} \frac{\rho_{\text{air}}}{\rho_{\text{water}}} \approx 2.0 \times 10^{-6} \]

- Sustained 60 mph wind, 5 mile fetch, 10 ft depth = 1.3 ft setup.
- At 30 ft depth = 0.4 ft setup
- Fetch limited waves, wind in m/s (1 m/s = 2.2 mph)
Polder Surge JPA—Inundation Hazards

- Polder surge inundation hazards are separate from other polder flood hazards:
  - Tropical rainfall-only flooding—Tropical Storm Allison
  - Non-tropical rainfall only—May 1995 Flood
  - Mississippi River flood

- Sources of polder surge inundation pose different threats
  - Individual seepage locations
    - <0.1 cfs/ft (43.6 acre-ft/mi-hr).
  - Minor-to-moderate overtopping
    - >0.1 cfs/ft for positive freeboard with small waves
      - Up to 4 cfs/ft (1,745 acre-ft/mi-hr) for a $R_c$ 1 ft.
    - The highest hazard posed by major overtopping and breaching
      - > 20 cfs/ft (8,727 acre-ft/mi-hr) $R_c$ >>1 ft.
Polder Surge JPA—Inundation Hazards

Five simplified 6-hr inflow scenarios are:

1. Multiple Seepage/Small Wave Overtopping
   785 acre-ft
   0.1 cfs/ft; 3 mi

2. Moderate Wave-Only Overtopping
   3,924 acre-ft
   0.5 cfs/ft; 3 mi

3. Overtopping
   7,855 acre-ft
   1 cfs/ft; 3 mi

4. Major Breach
   19,835 acre-ft
   20 cfs/ft; 2,000 ft

5. Multiple Major Breaches
   99,174 acre-ft
   20 cfs/ft; 10,000 ft
Polder Surge JPA—Polders
# Polder Surge JPA—Inundation Hazards

<table>
<thead>
<tr>
<th>Polder</th>
<th>Sub-Basin</th>
<th>Area</th>
<th>6-hr Duration</th>
<th>24-hr Duration</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Acres</td>
<td>10-yr 6.5 In</td>
<td>100-yr 10 In</td>
</tr>
<tr>
<td>New Orleans</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>East</td>
<td></td>
<td></td>
<td>10-yr 6.5 In</td>
<td>100-yr 10 In</td>
</tr>
<tr>
<td>NOE1 Maxent Lagoon</td>
<td>14,233</td>
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<td>7,710</td>
<td>11,861</td>
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<tr>
<td>NOE2 Maxent Wetland</td>
<td>5,683</td>
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<td>3,078</td>
<td>4,736</td>
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<tr>
<td>NOE3</td>
<td>2,866</td>
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<td>1,552</td>
<td>2,388</td>
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<tr>
<td>NOE4</td>
<td>2,338</td>
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<td>1,266</td>
<td>1,948</td>
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<td>14,792</td>
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<td>Total Polder*</td>
<td>34,708</td>
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<td>18,800</td>
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Acre-Feet Excluding Losses
Polder Surge JPA—Inundation Hazards

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<th>Polder</th>
<th>Sub-Basin</th>
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<th>24-hr Duration</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>10-yr 6.5 In</td>
<td>100-yr 10 In</td>
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<tr>
<td>Lower 9th Ward/St. Bernard</td>
<td>SB2 Central Wetland</td>
<td>5,066</td>
<td>2,744</td>
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<td></td>
<td>SB5 Central Wetland</td>
<td>24,340</td>
<td>13,184</td>
<td>20,283</td>
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<td></td>
<td>SB1</td>
<td>5,115</td>
<td>2,771</td>
<td>4,263</td>
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<td></td>
<td>SB3</td>
<td>5,485</td>
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<td>SB4</td>
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<td>Total Polder*</td>
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<td>26,770</td>
<td>41,184</td>
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Acre-Feet Excluding Losses
### Polder Surge JPA—Inundation Hazards

<table>
<thead>
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<th>Polder</th>
<th>Sub-Basin</th>
<th>Area</th>
<th>6-hr Duration</th>
<th>24-hr Duration</th>
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<tr>
<td></td>
<td></td>
<td>Acres</td>
<td>10-yr</td>
<td>100-yr</td>
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<tr>
<td></td>
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<td>6.5 in</td>
<td>10 in</td>
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<tr>
<td>Metro New Orleans</td>
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<tr>
<td>SC1 (mostly swamp)</td>
<td>SC1 &amp; 2*</td>
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<td>3,199</td>
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<td>3,989</td>
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<td>JE1</td>
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<td>OM5</td>
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<td>9,390</td>
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<td></td>
<td>OM 1, 2, 3, 4, 5*</td>
<td>27,288</td>
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<tr>
<td><strong>Total Polder</strong></td>
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<td>69,227</td>
<td>37,488</td>
<td>57,689</td>
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Acre-Feet Excluding Losses
### Polder Surge JPA—Inundation Hazards

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<thead>
<tr>
<th>Polder</th>
<th>Sub-Basins</th>
<th>Inundation Peak</th>
<th>Source of Inflow %</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Time</td>
<td>SWL Ft NAVD88</td>
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<tr>
<td>Metro New Orleans</td>
<td>OM1, 2, 3, 4 &amp; 5</td>
<td>Late Afternoon 8/30</td>
<td>2.5 to 3</td>
</tr>
<tr>
<td>Lower 9th Ward/St. Bernard</td>
<td>SB1, 3, 4</td>
<td>Before Noon 8/29</td>
<td>10 to 12</td>
</tr>
<tr>
<td>New Orleans East</td>
<td>NOE3</td>
<td></td>
<td>High Water Marks Not Available</td>
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<td></td>
<td>NOE4</td>
<td>Before Noon 8/29</td>
<td>2 to 2.5</td>
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<td></td>
<td>NOE5</td>
<td>Before Noon 8/29</td>
<td>-1.5 to -1</td>
</tr>
</tbody>
</table>
Polder inundation hazard cannot be evaluated by simply routing the exterior surge hazard—e.g., routing the perimeter 500-yr SWLs to determine an internal 500-yr inundation hazard.

A single storm is highly unlikely to produce a consistent 500-yr surge level along the entire perimeter system.

Furthermore, for large polders segments of the perimeter system have some independent exposure.

It follows that the occurrence of a 500-yr exterior SWL along one segment may produce an interior volume that actually has a much lower return period.

Quantifying polder inundation probabilities associated with hurricane surge events requires expanding the JPA for exterior surge approach described in Part III.

- Prepare a JPM set of exterior whole-perimeter surge events
- Define a range of scenarios to reflect SOBRP probabilities for each whole-perimeter surge event
- Numerically integrate the resulting PDF to produce the CDF curve,
Polder JPA: Perimeter Surge Events

- Need a set of *Whole Perimeter* Surge Events that represents the long-term probabilities of various combinations of perimeter conditions.
- Interested in events with conditions that could trigger inflow into polder for at least one location.
- With sufficient number of events—can compute internal inundation probabilities
- **Surge Response-OS set cannot be used—because the set does not represent probabilities.**
- The set of events needs to reflect complex local surge responses—e.g., “filling and tilting” combinations for Lake Pontchartrain.
- Need to assess local SWL hydrographs and foreshore wave conditions for each reach, for each event.
Polder JPA: SOBRP Scenarios

- For each JPM storm—with climatological joint-probability $p$—the whole-polder SOBRP subsets are defined:
  - Seepage can be neglected except with respect to breach probability.
  - Overtopping can be treated as deterministic.
  - Breaching scenarios usually limited to a few steps and simple probabilities (fragility).
  - Rainfall and pumping can be probabilistic, or simplified to be deterministic.
  - If focus is on extreme inundation hazard—i.e., major breaching—smaller inflow processes can be ignored.

- Either full, Monte Carlo, or optimized SOBRP subsets.
- Each scenario in subset has probability $p^*$, a fraction of storm $p$.
- Need 100s – 1000s of SOBRP scenarios, each with internal routing, per storm.
- During most storms many reaches won’t be active.
- May also need to consider interior wind setup.
Polder JPA: Preparation of Return Frequency Curves

- Results for all storm-SOBRP combination (each with discrete probability $p^*$) are integrated to provide polder surge inundation CDF.
  - Usually some spatial smoothing.
  - Also construct confidence intervals.
  - Can’t really validate polder inundation CDFs
Polder JPA: Wave Hazard

- For large open water bodies (canals) and open inundated areas: assess wave hazard associated with particular inundation SWL hazards.
- Similar to assessing exterior wave hazards.
- Can use analytical approaches (CEM), WHAFIS, or more complex models.
Recent Applications: 2009 IPET Vol. 8

- Only true polder inundation JPA to date.
- Reasonable first try for a “planning level” analysis.
- Compared pre-Katrina HSDRRS risk and reliability versus the 2007 post-Katrina reconstructed HSDRRS and planned 2010 HSDRRS (also referred to as 2011).
- 2010 HSDRRS did not include Barriers and several upgrades.
- There has been no completed update for the final HSDRRS as designed and constructed.
Recent Applications: 2009 IPET Vol. 8

- “Improvised” whole-perimeter events using 76 of 152 FIS storms.
- But set over-represents $V_{\text{max}} < 200\text{yr}$ & under-represents at $> 200\text{yr}$
- **IPET surge hazard estimates differ from FIS estimates!**
- Wave $H_s$ at $0.43 \times \text{depth}$
- SOBRP included overtopping and very simple breach failure rules and fragility
- Simple rainfall, pumping, and 1D routing with sub-basins.
# Recent Applications: 2009 IPET Vol. 8

<table>
<thead>
<tr>
<th>Polder</th>
<th>Sub-Basin</th>
<th>Acres</th>
<th>100-Yr Inundation Hazard</th>
<th>500-Yr Inundation Hazard</th>
<th>6-hr/100-yr Rainfall Minus 6-hr Pumping Acre-ft</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Elev</td>
<td>Vol Acre-ft</td>
<td>Elev</td>
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<td>New Orleans East</td>
<td>NOE1 Maxent Lagoon</td>
<td>14,233</td>
<td>0</td>
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<td>NOE3</td>
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<td>14,792</td>
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<td>4,927</td>
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## Recent Applications: 2009 IPET Vol. 8

<table>
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<tr>
<td></td>
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<td></td>
<td>Elev</td>
<td>Vol Acre-ft</td>
<td>Elev</td>
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<tr>
<td>Lower 9th Ward/St. Bernard</td>
<td>SB2 Central Wetland</td>
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<td>2</td>
<td>2,475</td>
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<tr>
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<td>SB5 Central Wetland</td>
<td>24,340</td>
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<td>21,764</td>
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<tr>
<td></td>
<td>SB1</td>
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<tr>
<td></td>
<td>SB3</td>
<td>5,485</td>
<td>-3</td>
<td>593</td>
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<tr>
<td></td>
<td>S94</td>
<td>9,413</td>
<td>1</td>
<td>1,480</td>
<td>4</td>
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<td></td>
<td><em><em>SB1. 3. 4</em> within 40 Arpent Levee</em>*</td>
<td>20,015</td>
<td>2,015</td>
<td>51,142</td>
<td>16.679 – 4.518 = 12,161</td>
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### Recent Applications: 2009 IPET Vol. 8

<table>
<thead>
<tr>
<th>Polder</th>
<th>Sub-Basin</th>
<th>Acres</th>
<th>100-Yr Inundation Hazard</th>
<th>500-Yr Inundation Hazard</th>
<th>6-hr/100-yr Rainfall Minus 6-hr Pumping</th>
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<tbody>
<tr>
<td></td>
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<td>Elev</td>
<td>Vol Acre-ft</td>
<td>Elev</td>
<td>Vol Acre-ft</td>
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<td>SC1 &amp; 2*</td>
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<td>10,232</td>
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<td>24,695</td>
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<td>25,322</td>
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<td>JE1, 2, 3*</td>
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<td>8,761</td>
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<td>12</td>
<td>1</td>
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<td>16</td>
<td>-2</td>
<td>2,638</td>
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<td>OM1, 2, 3, 4, 5*</td>
<td>27,268</td>
<td></td>
<td>1,463</td>
<td>7,290</td>
<td>22,773 - 12,774 = 9,999</td>
</tr>
</tbody>
</table>
Recent Applications: CPR Study

- Not a true JPA—simply employed the exterior 100-, 400-, and 1000-yr SWLs as whole perimeter events; three “pseudo-events” instead of large set of storms.
- But NOT real events—much higher real return period.
- But useful for “what if” comparisons.
- Used Surge Response-OS approach.
- 2010 HSDRRS case included GIWW/IHNC Surge Barrier but not Seabrook or raised West Return Wall.
- Reran only 48 of the 152 storms for changed HSDRRS and landscapes. Made “adjustments” to other storm results.
- Followed 2007 CDF process and added uncertainty factor.
- Wave $H_s$ at 0.40*depth.
- SOBRP included overtopping, rainfall, pumping, but no seepage or breaching; 1D routing with sub-basins.
Recent Applications: CPR Study

- 1000-yr hazard level completing around the perimeter.
- 2010 HSDRRS and landscape case.
Recent Applications: HSDRRS Design

**Current 100-yr SWL**

- Reran 56 storms run on the 2010 mesh (6 more than the 48 used for the CPR Study).
- The other 106 were “adjusted” to 2010 conditions.
- Reflects important limitations in:
  - The treatment of regional hurricane climatology.
  - The ADCIRC mesh—some local bias.
  - 2010 mesh had GIWW/IHNC Barrier but not Seabrook Barrier or West Return Wall upgrade;
  - The Surge Response-OS approach and the particular Surge Response-OS set.
  - The CDF integration method with modest increase in the estimated 100-yr surge hazard.
- Little to no difference between 2007 and 2010 100-yr SWLs along Lake Pontchartrain; but increases near barrier.
- 100-yr SWL confidence limits similar to 2007. For 10 ft surge, \( \sigma = 2.3 \) to 4.1 ft; 90% CI = ±3.8 to 6.8 ft
Recent Applications: HSDRRS Design
Recent Applications: HSDRRS Design
Recent Applications: HSDRRS Design

**Current 100-yr Waves**
- Wave $H_S$ at 0.40*depth; $T_p$ from STWAVE

**Wave $H_S$, and $T_p$ within the IHNC/GIWW sub-basin**
- Bretschneider Equation, 1% wind speed of 77 mph; most fetches at 0.5 mi.
- $H_S$ and $T_p$ of 3 ft and 3.5 s.
- For northern and southern reaches along the IHNC a 0.25 mi fetch was utilized, yielding $H_S$ and $T_p$ of 3 ft and 3.5 s
- Wind setup, as well as more extreme wave conditions, produced along the 6+ mi GIWW fetch—similar to what was observed with Hurricane Gustav, but with the barriers closed—was **NOT** considered.
Recent Applications: HSDRRS 100-yr Design

100-yr SWL and waves in the Mississippi River

- Supplementary JPM Surge Response-OS analysis.
  - Revised the JPA expression to incorporate a probability for the river discharge by month, together with the hurricane landfall frequency by month.
  - Modified the Surge-Response function to include Mississippi River discharge.
  - Improved ADCIRC-STWAVE mesh with greater river details.
  - Recomputed CDFs for points along the river.
  - Did an IPET-style JPA for 100-yr return frequency waves along the river levees.
  - The breaking parameter was used to reduce waves as appropriate.

- The small set size may not sufficiently capture critical wind setup variations in the Mississippi River. Storm set is not representative of more extreme hazards.
Recent Applications: HSDRRS Design

Hydraulic Design Criteria

- Crowns required to be >2 ft above the median (50% Exceedance Level) estimated 100-yr SWL. \textbf{Design elevations based on wave overtopping.}
- Wave overtopping (Van der Meer & Franco) estimated for 100-yr SWL, \( H_s \), and \( T_p \), together with assigned normally distributed uncertainty factors, \( \sigma \), for each value.
- Median estimate of local average overtopping used to adjust crown to limit 100-yr average overtopping for levees & floodwalls at 0.01 & 0.03 cfs/ft.
- \( \sigma \) factors employed with a Monte Carlo technique to determine local average overtopping rates at the 10\% Exceedance Level. Crowns raised as necessary to limit the this overtopping at 0.1 cfs/ft.
Recent Applications: HSDRRS Design

**Hydraulic Design Criteria—Continued**

- Basis is scour limit for the average overtopping.
- But peak scour velocities can be 150x higher than average velocities—wave overtopping scour needs research.
- Median and 10% criteria yield low local volumes.
- But no JPA and no assessment of 100-yr polder volumes.
- Final crown design may be higher than hydraulic criteria due to geometry requirements and construction overbuild.
Recent Applications: HSDRRS Design

- **Design very sensitive to change in 100-yr SWL, \( \sigma_{SWL} \), \( H_s \).**
- Surge model validation local SWL bias >1.5 ft; but 100-yr SWLs also have built in uncertainty adjustment (up to 0.4 ft)
- \( \sigma_{SWL} \) NOT the statistical uncertainties noted earlier—often less than 10% compared to 20 to 30%.
- \( H_s \), determined by Breaking Parameter of 0.4; low end value and not much research; Rayleigh distribution may not apply.
Recent Applications: HSDRRS Design

- 100-yr criteria provides equal 100-yr overtopping hazard at all reaches (based on levee or floodwall type).
- However, they necessarily translate into *widely varying 100-yr freeboards*.
- Reaches fronted by vast foreshore wetlands require less freeboard to minimize wave overtopping.
- Reaches immediately fronted by a large water body necessitated more freeboard to minimize wave overtopping.
Recent Applications: HSDRRS Resiliency

**Current 500-yr SWL overtopping rate—limitations**
- Surge Response-OS underestimates extreme surge hazards.
- Does not provide a minimum freeboard criteria for the 500-yr condition.
- Design guidance stated that elevation is to prevent free flow for the 500-yr condition (the exceedance level is not specified.)
- However, the guidance on HSDRRS elevation did not provide for raising reach elevations based on the evaluation of the 500-yr condition.
- **East-bank St. Charles Parish levee reach east of I-310 has 500-yr design freeboard of only 0.5 ft**
Recent Applications: HSDRRS Resiliency

- At 500-yr condition, unlike 100-yr condition, reaches have different overtopping rates.
- Reaches with minimal 500-yr freeboard face the most significant exposure.
- Especially affects 10% Exceedance Overtopping
Recent Applications: HSDRRS Resiliency

**Appropriate interior-side armoring measures to reduce the threat of overtopping induced erosion breaching.**

- Varying overtopping rates above the 100-yr hazard mean that different reaches have significantly different erosion breach probabilities at hazards above the 100-yr level.
- The USACE is presently evaluating alternative armoring technologies (enhanced turf, turf reinforcement mats, concrete mats, armor stone, etc.) for different overtopping conditions.
- Some effort to use IPET JPA approach to compare alternatives.
- Draft evaluation does not factor in 500-yr overtopping uncertainty.
Recent Applications: HSDRRS Resiliency