Influence of Wetland Degradation and Restoration on Storm Surge

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Team Effort

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Purpose/Motivation

- Complicated Dynamics preclude application of simple “rules of thumb” (i.e. X miles of marsh reduces surge by Y feet)
  - Storm track
  - Storm intensity
  - Surrounding topography/bathymetry
  - Vegetation type

- Apply numerical models to assess the potential of wetland features for reducing storm surge.

- Trends and relative performance.

- Modeling is a tool for qualitative and/or semi-quantitative evaluation of the surge reduction
Methodology

- Apply integrated modeling system.
- Modify bathymetry and friction fields to represent wetland degradation and restoration.
- Compute statistical surfaces with JPM-OS methodology.
- Compare results to base condition.
Summary of Conclusions

• Simulations indicate that vegetated landscape features do have surge reduction potential.
• Can not apply a simple “rule of thumb” to quantify surge reduction potential of wetlands.
• Impact can be amplified in areas with levee “pockets”.
• Large continuous restorations provide maximum benefit.
• More research and data is needed.
Storm Surge and Wetlands

• Considered:
  – Bathymetry and topography act as physical barrier and create bathymetric resistance.
  – Vegetation reduces surface winds and slows surge propagation.

• Not Considered:
  – Changes to the landscape that occur during storms passage (ie vegetation stripped, land mass eroded)
  – Changes in the structure of the hurricane itself due to landfall infilling phenomenon that may be influenced by landscape features
Wetland Changes - Model

• Restoration/Degradation impacts on surge:
  – Depth
  – Wind (surface roughness and canopy)
  – Bottom Friction (through simple Manning formulation)

• Codes and methodologies developed to modify the ADCIRC grid and input friction files directly.
Sensitivity Demonstration

Lower Biloxi marsh to 2 ft below MSL
Sensitivity Demonstration

HUR1 (Hurricane Hilda-like)
- Central Pressure: 960 mb
- Rmax: 22 nm
- Forward Speed: 11 knots

HUR2 (Hurricane Katrina-like)
- Central Pressure: 900 mb
- Rmax: 22 nm
- Forward Speed: 11 knots
Biloxi Degradation

Surge: Degraded - Base

HUR1

HUR2
Wetland Change Scenarios

• Future “Degraded”: Based on 50-year “No Increased Action” landscape prediction from the Coastal Louisiana Ecosystem Assessment and Restoration (CLEAR) model.

• Restored: Based on plan developed by Federal and State interests.
Future No Increased Action Coastal Landscape
CLEAR Output => ADCIRC

CLEAR Input Cell Year 0
- LULC Data at 25m Res
- Each node falls in one habitat type

CLEAR Output Cell Year 50
- Spatial uncertainty

Most likely candidates for change from water to fresh marsh as they were the shallowest nodes in Year 0

Credit: Brady Couvillon, USGS National Wetlands Research Center
NLCD/GAP Source Datasets Updated for Manning-n and z0

NLCD/GAP Data Year 0

CLEAR Output Cell Year 50
Spatial uncertainty - 75% Fresh Marsh
25% Water

CLEAR 50 Yr Model Run

50% increase in Fresh Marsh

Marsh retreat/advance occurs from water’s edge
Future Degraded Landscape Changes

Bathymetry Difference
Future Degraded Landscape Changes

Manning n Difference
Restored Landscape

Based on type
1-Saline, n=0.035, z0=0.11
2-Intermediate, n=0.040, z0=0.11
3-Brackish, n=0.040, z0=0.11
4-Freshwater, n=0.045, z0=0.11
5-Wetland forest, n=0.15, z0=0.55

Modified:
- bathy/topo (~+1.5 ft NAVD88)
- Mannings-n
- Wind reduction factor
  \[ \text{Based on type} \]
Restored Marsh

- **Procedure**
  - Spatial extent of wetland restoration determined
    - Constructed – given
    - Sediment Diversions
      - “Volume” of land created and diversion location is given and the marsh is built radially outward until given volume is achieved.
    - Bathy/topo raised to healthy marsh level
    - Manning n updated
    - Canopy updated
    - Directional roughness lengths calculated

Local
Directional Roughness Lengths

• Wind Reduction
  – Winds are reduced to account for higher surface roughness through a directional land masking procedure
Because nodes are not equally distributed on the unstructured grid, an area weighted average method is used to compute the final inversed distance weighted $z_0$.

Bins created based on distance from node to be updated

A $z_0$ is computed for each bin

Final $z_0$ is the area weighted average
Restored Landscape Changes

Bathymetry Difference
Restored Landscape Changes

Manning n Difference
Storm Simulations

• Future No Increase Action
  – 152 storms, statistical analysis performed

• Restored Landscape
  – 24 storms simulated
Restored Landscape

Peak of Peak Difference Plots

Less than 0.5 ft change east of river

1 to 2 ft change in the Houma area
Future Degraded Landscape

Change in 100-yr level
Future Degraded Landscape

Change in 100-yr level

Marepaus ~1 ft
West Bank ~1 to 1.5 ft
Funnel ~0.75 ft
Caernarvon ~0.5 ft
Little change in Ponchartrain
Summary

• Simulations indicate that vegetated landscape features do have surge reduction potential.
• Based on these simulations, 100-yr levels are increased for the future degraded condition by as much as 1.5 ft at the West Bank, otherwise differences are generally 0.5 ft or less.
• Impact can be amplified in areas with levee “pockets”, indicating that these may be the best area for targeted restoration activities.
• Large continuous restorations provide maximum benefit, significant change would require restoration efforts at the landscape scale.
• Lesson: Keep what you have.
• More data and research is needed.
Lake Borgne Measurements

- Measure wave attenuation and water levels across wetlands
  - Four non-directional wave/water level gauges
  - Anemometer
  - Characterization of wetland (elevation, plant type, plant density, plant height, …)
Lake Borgne Deployment

1000-2000 ft of wetland lake-ward of Gauges 2, 3, and 4.

Gauge 1 is reference.
End
Parameterizations of Frictional Resistance

• Wind Reduction
  – Winds in ADCIRC and STWAVE are reduced to account for higher surface roughness through a directional land masking procedure.

\[ f_r = \left( \frac{z_{0_{\text{marine}}}}{z_{0_{\text{land}}}} \right)^{0.0706} \]

Roughness length scales

\[ z_{0_{\text{marine}}} = \frac{\alpha_c C_d W_{10}^2}{g} \]

\[ \alpha_c = 0.18 \] (Charnock parameter)

As inundation takes place, roughness is reduced

\[ z'_0 = z_{0_{\text{land}}} - \frac{d}{30} \quad \text{for} \quad z'_0 \geq z_{0_{\text{marine}}} \]
Parameterizations of Frictional Resistance

• Wind Reduction
  - Winds in ADCIRC and STWAVE are reduced to account for higher surface roughness through a directional land masking procedure
Parameterizations of Frictional Resistance

• Wind Reduction
  – A canopy is applied to areas classified as NLCD/GAP forest precluding momentum transfer from the wind fields to the water column
Parameterizations of Frictional Resistance

- Manning-n scalar parameterization used to approximate flow resistance from a variety of physical mechanisms, including form drag, skin friction, and secondary currents.

Manning-n values for Louisiana GAP classes (FEMA 2005):

- defined at appropriate grid scale
- published values
- validated against hindcasts of hurricanes Katrina and Rita

\[
\begin{align*}
\text{n} & = 0.055 & \text{! fresh marsh} \\
\text{n} & = 0.050 & \text{! intermediate marsh} \\
\text{n} & = 0.045 & \text{! brackish marsh} \\
\text{n} & = 0.035 & \text{! saline marsh} \\
\text{n} & = 0.15 & \text{! wetland forest - mixed} \\
\text{n} & = 0.17 & \text{! upland forest - mixed} \\
\text{n} & = 0.18 & \text{! dense pine thicket} \\
\text{n} & = 0.020 & \text{! water}
\end{align*}
\]
Parameterizations of Frictional Resistance

• Factors influencing Manning-n value.

Turbulence $\uparrow \implies n \downarrow$

Veg “damage” $\uparrow \implies n \downarrow$

Modeling a 3D process with a depth-integrated model?? $\implies n \downarrow$

More data needed!
STWAVE

• Restoration impacts on nearshore waves:
  – Depth (refraction, shoaling, **breaking**)
    • Still-water depth
    • Surge
  – Wind (generation)
  – Friction (through Manning formulation, dissipation is a function of water depth and vegetation type)

\[ S_{bf} = -\frac{1}{g} \left( \frac{g n^2}{d^{1/3}} \right) \frac{\sigma^2}{\sinh^2 kd} E(f, \alpha) u_{rms} \]

Spectral-based dissipation source term
Holtuijsen (2007)
Wetland Conditions

- Base Condition
- Caernarvon marsh restoration and deterioration
- Biloxi marsh restoration and deterioration
- Coast-wide restored marshes
- Future No Increased Action coastal landscape.
Wetland Restoration/Degradation

Caernarvon
Restored: ~+0.33 m (NAVD88), Intermediate marsh
Degraded: ~-0.6 m (NAVD88), Open water

Biloxi
Restored: ~+0.33 m (NAVD88), Brackish marsh
Degraded: ~-0.6 m (NAVD88), Open water
Storm HUR1

HUR1 (Hurricane Hilda-like)
- Central Pressure: 960 mb
- Rmax: 22 nm
- Forward Speed: 11 knots

Peak Surge

2.5 m
1.5 - 2 m
Storm HUR2

HUR2 (Hurricane Katrina-like)
- Central Pressure: 900 mb
- Rmax: 22 nm
- Forward Speed: 11 knots

Peak Surge

4 – 4.5 m
2 – 3.5 m
Max Wave Height HUR2

Max Wave Height (m)

H=16m
Caernarvon Restoration

Surge: Restored - Base

Peak Water Level Difference (m)

-2.5  -2.0  -1.5  -1.0  -0.5  0.0  0.5  1.0  1.5  2.0  2.5

-30%  -25%  -20%  -15%  -10%  -5%  0%  5%  10%  15%  20%  25%  30%

HUR1  HUR2
Caernarvon Restoration

Waves: Restored - Base

Max Wave Height Difference (m)

HUR1

HUR2
Caernarvon Degradation

Waves: Degraded - Base

Max Wave Height Difference (m)

HUR1

HUR2
Biloxi Restoration

Surge: Restored - Base

HUR1

-5 to 10%

-15%

HUR2

-10%

-20%

-30%
Biloxi Restoration

Waves: Restored - Base

Max Wave Height Difference (m)

HUR1

HUR2
Biloxi Degradation

Surge: Degraded - Base
Biloxi Degradation

Waves: Degraded - Base

Max Wave Height Difference (m)

HUR1

HUR2
Restored Landscape

1-Saline, n= 0.035, z0=0.11
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Modified:

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Restored Landscape

Surge: Restored - Base

HUR1

HUR2
Future NIA Landscape Changes

CLEAR => Coastal Louisiana Ecosystem Assessment and Restoration

Topo/Bathy updated by Brady Couvillon, USGS National Wetlands Research Center

purple = degraded
blue = improved
Future NIA
Future NIA
Plan/Progress

• Workshop – held March, 2006
• Literature Review
• Initiate data collection efforts
• Coast-wide numerical assessment
  – Degraded (or No Increased Action)
  – Restored
• “Numerical experiments”
  – Sensitivity to isolated landscape features
  – Sensitivity with Idealized grid setup