Time: The Fourth Dimension of Hazard Mitigation Planning

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Time: The Fourth Dimension of Hazard Mitigation Planning

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2013 Disaster Resilient Universities Workshop
Lindy C. Boggs Conference Center
Thursday, March 21, 2013

\textsuperscript{1}LSU AgCenter
\textsuperscript{2}LA Sea Grant
\textsuperscript{3}LSU Center for Geoinformatics
A Landscape Vulnerable to Inundation

South of Chauvin, Louisiana
Terrebonne Parish

Photo provided by Terrebonne Levee & Conservation District
A Landscape Subsiding into the Gulf

Tropical Storm Lee Inundates LA Hwy-1

Photo by Tim Osborne (NOAA)
A Landscape of Vulnerable Communities

Water swamps tombs at this 105 year old cemetery in Leeville, LA

(© James Wray/ EPA/BEVIL KNAPP, 2010)
A Landscape of Contradictions
A Landscape Vanishing...

Relative Sea-Level Rise >10mm yr\(^{-1}\)

- 16.5 mi\(^2\) yr\(^{-1}\) land loss per year*
  - 1 football field every 60 min since 1985
- Louisiana lost 1.2 million acres in the last century
- Louisiana has ~40% of the Nation’s coast and 80% coastal land loss in the lower 48 states.

* USGS | Couvillion et al., 2011

Projected 10 sqmi/yr Land Loss by 2050 (Barras, 2004)

Subsidence has lowered evacuation roads throughout coastal Louisiana

La Hwy 1 sank ~1 foot between 1982 and 2002

Hurricane Induced Land-Water Change (Barras, 2006)
Lafourche Interactive Flood Mapping Site

While the floodplain data that is shown on this map is the same, this map is not an official FEMA Preliminary Digital Flood Insurance Rate Map (DFIRM). This Interactive Mapping Tool is not intended for insurance rating purposes and is for information only. The pin on address may not be 100% accurate in locating your address. Please contact your local floodplain administrator for more information or to view an official copy of the Preliminary Digital Flood Insurance Rate Map (DFIRM).

DFIRM Legend

Water Features
- Dasso Flood Elevation
- Zone Break
- Zone A, AE, VE, 1% Annual Chance Flood Hazard
- Floodway within Zone A, AE, VE
- Zone X, 0.2% Annual Chance Flood Hazard

Points Info

Point 1
Latitude: 29.71543
Longitude: -90.61348

For contact information on community officials click here
Flood Insurance Study Text
What’s my new Zone and Base Flood Elevation? How to read the new DFIRMs
LaFourche Interactive Flood Mapping Site

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DFIRM Legend

- Water Features
- Base Flood Elevation
- Zone Break
- Zone A, AE, VE, 1% Annual Chance Flood Hazard
- Floodway within Zone A, AE, VE
- Zone X, 0.2% Annual Chance Flood Hazard

Panel ID: 220511J02b8
FIRM Zone: Read from map
Ground Elevation: 3.47 ft

Meetings
Events

For contact information on community officials click here
Flood Insurance Study Text
What’s my new Zone and Base Flood Elevation? How to read the new BFRMs
Ground Elevation: 3.47 ft
Wind Speed ('06-'12): 123 mph
Fourth Dimension:

TIME!

In 50, 60, or 70 years, what will that elevation be, and how will it compare to sea level at that time?
Relative Sea-Level Rise Components

Current Sea Level Elevation
Relative Sea-Level Rise Components
Relative Sea-Level Rise Components

Increasing Sea Level Elevation
Relative Sea-Level Rise Components
Relative Sea-Level Rise Components

Increasing Sea Level Elevation
Relative Sea-Level Rise Components

Increasing Sea Level Elevation

+ Decreasing Land Surface Elevation
Relative Sea-Level Rise Components

- Increasing Sea Level Elevation
- Decreasing Land Surface Elevation

March 21, 2013

2013 DRU Workshop | Lindy C. Boggs Conference Center
Relative Sea-Level Rise Components

Increasing Sea Level Elevation + Decreasing Land Surface Elevation
Consequences to Sustainability

The adverse effects of continued development that increases run-off, decreased flood storage capacity, absolute sea level rise, disappearing wetlands, and the complicated issue of subsidence impacts our ability to develop a meaningful instrument for assessing flood risk.
Time: the 4th Dimension of Mitigation Planning in Louisiana

- **Identify rates of subsidence** in Louisiana, the evidence of subsidence, factors influencing subsidence (including the ties to levees and drainage), and examples of possible long-term consequences.

- Illustrate how **collaboration between the LA Sea Grant, LSU AgCenter and LSU Center for Geoinformatics** combines the University’s continuously operating GPS reference stations (CORS) with flood risk forecasting that makes the information and evidence of subsidence **more accessible to the people of Louisiana**.

- Demonstrate how this information, in combination with the Flood Insurance Rate Map, **provides a more complete picture of future risk**.
Relative sea level rise, subsidence, coastal land loss, and storm surge inundation **conspire to make existing risk-assessment strategies inadequate** for regulating development - especially development that should have a meaningful life expectancy.
Elevation – Coastal LA. Is LOW
LIDAR Surface Elevation

Elevation - Feet
- < 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 20
- 20 - 40
- 40 - 68
- WATER
Elevation In Coastal LA Is Deceptive

U. S. Hwy. 90 Gulfport to Biloxi

Mississippi Sound
Elevation In Coastal LA Is Deceptive

U. S. Hwy. 90 Gulfport to Biloxi
Elevation In Coastal LA Is Deceptive

U. S. Hwy. 90 Gulfport to Biloxi

Avg. Elev. 10.3 Ft.
OUT OF SIGHT – OUT OF MIND?

St. James Parish – Hwy 3127
45 Miles from GOM

Avg. Elev. 7.1 Ft.
OUT OF SIGHT – OUT OF MIND?

St. John Parish – Hwy 3127
50 Miles from GOM

Avg. Elev. 5.0 Ft.
OUT OF SIGHT – OUT OF MIND?

Lafourche Parish – U. S. Hwy 90
32 Miles from GOM

Avg. Elev. 4.8 Ft.
OUT OF SIGHT – OUT OF MIND?

St. Mary Parish – U. S. Hwy 90
10 Miles from GOM

Avg. Elev.
7.8 Ft.
Elevation In Coastal LA Is Deceptive

All Elevations Lower Than U. S. 90 Biloxi - Gulfport
AND GETTING LOWER!

The map above illustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.

Sea Level Trends
mm/yr (feet/century)

- 9 to 12 (3 to 4)
- 6 to 9 (2 to 3)
- 3 to 6 (1 to 2)
- 0 to 3 (0 to 1)
- -3 to 3 (-1 to 1)
- -6 to 0 (-2 to 0)
- -9 to -6 (-3 to -2)
- -15 to -12 (-5 to -4)
- 9 to 12 (3 to 4)

Global Stations
Global Sea Level Trend Table in mm/yr
Global Sea Level Trend Table in feet/century

The Center for Operational Oceanographic Products and Services has been measuring sea level for over 150 years, with tide stations of the National Water Level Observation Network operating on all U.S. coasts. Changes in Mean Sea Level (MSL), either a sea level rise or sea level fall, have been computed at 128 long-term water level stations using a minimum span of 30 years of observations at each location. These measurements have been averaged by month to remove the effect of higher frequency phenomena in order to compute an accurate linear sea level trend. The trend analysis has also been extended to a network of global tide stations.
The map above illustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.

Sea Level Trends

3.17 ft. / 100 yrs.

3.03 ft. / 100 yrs.

The Center for Operational Oceanographic Products and Services has been measuring sea level for over 150 years, with tide stations of the National Water Level Observation Network operating on all U.S. coasts. Changes in Mean Sea Level (MSL), either a sea level rise or sea level fall, have been computed at 128 long-term water level stations using a minimum span of 30 years of observations at each location. These measurements have been averaged by month to remove the effects of higher frequency phenomena in order to compute an accurate linear sea level trend. The trend analysis has also been extended to a network of global tide stations.
Mean Sea Level Trend
8729840 Pensacola, Florida

1923 - 2011

0.7 Feet / 100 Years
Recent Sea Level Rise

23 Annual Tide Gauge Records
- Three Year Average
- Satellite Altimetry
NOAA/Laboratory for Satellite Altimetry
Gulf of Mexico
mean sea level anomaly
Annual signals removed

trend = 2.9 ± 0.4 mm/year
Eustatic Sea Level Rise

August 2002
Mean Sea Level Trend
8761724 Grand Isle, Louisiana

1947 - 2011

3.03 Feet / 100 Years

Grand Isle, LA
9.24 +/- 0.59 mm/yr

Source: NOAA
Mean Sea Level Trend
8761724 Grand Isle, Louisiana

1947 - 2011

3.03 Feet / 100 Years

Grand Isle, LA

9.24 +/- 0.59 mm/yr

Source: NOAA
Mean Sea Level Trend
8761724 Grand Isle, Louisiana

1947 - 2011

3.03 Feet / 100 Years

Grand Isle, LA
9.24 +/- 0.59 mm/yr

Source: NOAA
Impacts of Subsidence

Identify rates of subsidence in Louisiana, the evidence of subsidence, factors influencing subsidence (including the ties to levees and drainage), and examples of possible long-term consequences.

• Definition
• Processes
  – Natural
  – Anthropogenic
• Rates
Subsidence Impact on Urban Settings: New Orleans East...
Subsidence Impact on Surveying & Engineering
NOAA told the U.S. Congress in 2001 that the system used to measure elevations in LA was "...obsolete, inaccurate, and unable to support public safety."

Accurate elevations were not restored until 10/2005. Elevations obtained between 2001 and 2005 were highly suspect.

http://www.ngs.noaa.gov/PUBS_LIB/NGSexecsum_823.pdf
Understanding Subsidence

• “The downward movement of the Earth’s surface with respect to a datum.”
• Subsidence has been misunderstood because of differing measurement approaches and research focused on different process assumptions.
• Associated with any one or many natural and anthropogenic processes.
• Subsidence rates are 4D: and has been measured across south LA, MS, and TX.
• Subsidence rates are variable in time and space!
• mm/yr to several dm/yr.
Subsidence in Louisiana:

NOAA Tech. Rept. 50
Geodetic leveling shows that vertical motions vary in time and space.

Coastal Subsidence:
avg. -1/2 inch yr\(^{-1}\)
1960s-1980s
A Brief Geologic History of South Louisiana

- Modern Mississippi River delta formed >~8,000 bp
- The landscape was defined through processes of **subsidence**, **sediment accretion**, **global sea level rise**, and **hydrologic processes**.
- Land built by **sediment deposition** and wetlands growth **balanced by subsidence and eustatic rise**.
- **Deltas could not grow much above sea level**.
- When **delta lobs were abandoned**, accretion stopped and **subsidence and sea-level rise continued**.
- Over time, the lobes were slowly inundated by the Gulf.

Today, levees prevent flooding and accretion while erosion continues. **Subsidence and sea-level rise dominate.**
The Nuances of Subsidence

- Conventional wisdom considers subsidence to be *constant in time and space*.

- But, analysis of geodetic data as a function of depth shows that *subsidence is variable in time and space*.

- Therefore, to measure subsidence, we need a *better understanding of the processes* in order to design a proper measurement strategy.
Natural and Anthropogenic Processes that Result in Subsidence

• **Shallow Processes** (processes above aquifers):
  - **Natural Consolidation & Compaction**: ≤ 5 mm/yr
  - **Anthropogenic Consolidation & Compaction**: ~ 30 mm/yr
    - **Desiccation by urbanization** (behind levees) and reclamation.
    - **Soil Oxidation** of Organic Matter

*The dominant causes of subsidence in LA*
Shallow Subsidence: Consolidation & Compaction

Consolidation & Compaction Subsidence Rates:
0 to 5 mm yr⁻¹

- Chronostratigraphy: ≤ 5 mm yr⁻¹
- Numerical Models: ~ 3 mm yr⁻¹

A) Gravity pulls the overburden down, forcing consolidation by squeezing out water.
B) Continued pressure compacts the material under the weight of the overburden.

A. (Reed & Yuill, 2009)

B. Törnqvist et al., 2006

Meckel et al., 2006
Subsidence

Groundwater withdrawal, oxidation, and compaction of organic materials\(^a,b,c\):

\[ \leq 30 \text{ mm yr}^{-1} \]

1.18” per year

- Flood Protection
- Water Drainage & Management

\( ^a \) Deveral & Rojstaczer, 1996
\( ^b \) Stephens & Speir, 1969
\( ^c \) Snowden et al., 1968
Clovelly Farms
~8 ft of subsidence in 75 years

Building levees speeds up compaction, but may be the only way to provide protection to communities.
Examples of Shallow Subsidence

House built on piles (45ft deep) in 1964. The driveway, yard, and street have subsided over 2 ft (0.5 in/yr)
Monuments Reveal the Shallow Subsidence

- Virtually all BMs and CORS are partially affected.
- Region above producing aquifers.
- Most people assume all subsidence is only caused by shallow processes.

“It’s all about the monument...”
Deep Rods & Shallow Subsidence

Subsidence of Ground Surface between 1986 and 2008

1986
Ground Surface

Survey Disk
(typically set a few inches below surface)
PVC Casing

Subsiding Upper layer
(by compaction, dewatering, etc. + "deep" subsidence)

point on casing adjacent to original position of the disk

2008
Ground Surface

point on casing adjacent to original position of the disk

"Stable" lower layer
(only "deep" subsidence occur here)

point of refusal

***This is a cross-section.
Natural and Anthropogenic Processes that Result in Subsidence

• **Shallow Processes** (processes above aquifers):
  – Natural consolidation and compaction: ≤ 5 mm/yr
  – Human-induced consolidation and compaction*: ~ 30 mm/yr
    • Desiccation by urbanization (behind levees)
    • Organic Soil Oxidation

• **Deep Processes** (processes at & below aquifers):
  – **Load induced flexure** of the lithosphere: 0-8mm/yr
  – **Glacial Isostatic Adjustment**: 0.55-2.0mm/yr
  – **Faulting**: ≤ 20mm/yr (variable)
  – **Salt Evacuation**: 0 to ??mm/yr (variable)
  – **Water Pumping***:  ≤ 65mm/yr (variable)
  – **Oil & Gas extraction**: 0 to 3 mm/yr (variable)
Glacial Isostatic Adjustment

Weight of ice pushes earth’s crust downward

Downward displacement of the earth’s northern crust pushes up in southern areas
Thickness of the Mississippi River Delta

Holocene Sediment Thickness (m)
- 0 - 10
- 11 - 30
- 31 - 50
- 51 - 70
- 71 - 100

Kulp, 2000
Holocene Sediment Loading on the Lithosphere

Tectonic Loading explains well the deep subsidence recorded by CORS and Water Level Gauges.

- Rigoletts: -3.7 mm/yr
- Cocodrie: -6 mm/yr
- Grand Isle: -6 mm/yr

Ivins, Dokka, & Blom (2007)
Paris Rd. Bridge (LA-47): Subsided ~1m over 50 years
A tale of two CORS...

Two CORS sites located at the NASA’s Michoud Assembly Facility in New Orleans, LA.

• Measuring the differential changes in elevations between the CORS: one on a deep well casing, the other on a shallow concrete slab.
A tale of two CORS...
Seven months of differential motions between deep and shallow subsidence. MARY (on deep well) and MOON (on concrete slab).

NASA Michoud Assembly Facility Differential Motions (8/12 – 3/13)
Coastal Land Loss

Legend
- Parish Boundary
- Interstate
- U. S. Highway
- Major Road
Coastal Land Loss (1932 – 2000)

Legend
- Parish Boundary
- Interstate
- U. S. Highway
- Major Road
- 1932 - 2000 Loss
- 1932 - 2000 Gain
How does subsidence impact communities?
Land at or Below ‘Sea Level’

~10m USGS Composite DEM: 2002 - 2008

Vulnerable Land

- Below 0m NAVD-1988

National Elevation Dataset (NED)

Elevation (meters)

March 21, 2013
Land at or Below 0m NAVD88
~10m USGS Composite DEM: 2002 - 2008

Proportion of Land Below 'Sea Level'
by Parish Land Area

Area: ~680 miles²
Populations at or Below 0m NAVD88

2010 Census Demographics: Households ≤ Sea Level
2010 Population: 513,453 Live on Land Below ‘Sea Level’
Lafourche Parish Subsidence Rates
Lafourche Parish Area – Basemap with Levees
Areas With Elevations Below Water Level Elevation - 2020
Areas With Elevations Below Water Level Elevation - 2030
Areas With Elevations Below Water Level Elevation - 2040
Areas With Elevations Below Water Level Elevation - 2050
Relative Sea-Level Rise and Storm Surge

Current Sea Level Elevation
Relative Sea-Level Rise and Storm Surge

Moderate Storm Surge
Relative Sea-Level Rise and Storm Surge

Current Sea Level Elevation
Relative Sea-Level Rise and Storm Surge

Increasing Sea Level Elevation
Relative Sea-Level Rise and Storm Surge

Increasing Sea Level Elevation
Relative Sea-Level Rise and Storm Surge

Increasing Sea Level Elevation
Relative Sea-Level Rise and Storm Surge

Increasing Sea Level Elevation
Relative Sea-Level Rise and Storm Surge

- Increasing Sea Level Elevation
- Decreasing Land Surface Elevation
Relative Sea-Level Rise and Storm Surge

- Increasing Sea Level Elevation
- Decreasing Land Surface Elevation
Relative Sea-Level Rise and Storm Surge

- Increasing Sea Level Elevation
- Decreasing Land Surface Elevation
- Minor Storm Surge
Relative Sea-Level Rise and Storm Surge

- Increasing Sea Level Elevation
- Decreasing Land Surface Elevation
- Moderate Storm Surge
Strategies for Resiliency

- Mitigation Efforts
- Monitoring
- Science
- Outreach & Education
The Louisiana Legislature requested LSU measure the height of the South LA HPS in 2006-2007.

N = 50,000 points

Note: Does not reflect post 2007 construction by USACE
• Geometric accuracy is ~2cm horizontal and ~4cm vertical
• RTN Services based on the LSU CORS network.
• The most reliable and consistent component of the NSRS in Louisiana.
• Funded via Federal and Professional Partnerships
Katrina SLOSH model using outdated or assumed elevation data.

Example of Inaccurate vs. Accurate Elevation Estimates of the Flood Protection Systems.

Katrina SLOSH model using accurate elevation data.
NOAA’s Sentinels of the Coast

National Water Level Stations Designed to Survive Category 4 Hurricanes

Hardened Tide Station

Engineering Design

Equipment fabrication and staging in Berwick, LA
Elevated Platform Station
USCG New Canal
Station (New Orleans) installed after Hurricane Katrina
Texas NWLON
Elevated Platforms
Monitoring: Surge Measurements
Science & Engineering

• Inundation Modeling
  – Sea Lake & Overland Surges from Hurricanes (SLOSH)
  – ADvanced CIRCulation Models (ADCIRC)

• Geodetic Analysis
  – Height Modernization
  – Datum Adjustments
Monitoring Subsidence in New Orleans East

Subsidence measured across the coast:

- Example: a deep-set monument reveals subsidence related to aquifer discharge.
Use our knowledge of physical geodesy to provide more accurate and consistent orthometric elevations

- Make sure hurricane protection systems are designed and constructed to the appropriate heights
- Provide outreach for the effective use of Real-Time Kinematic Networks

Measurable differences between the 2009 and 2012 GEOID models:

- a range of nearly 1.0ft

Which model is correct?
Outreach & Education

• Flood Insurance Mapping
• Risk Avoidance Strategies
• CORS Best Practices
Conclusions

Sea Level Rise and Subsidence conspire to make existing risk-assessment strategies inadequate for regulating development.
Overview of the Hazards

- **Sea Level Rise** will continue to test both environmental and social resiliency to disasters.

- **Subsidence Rates** vary across the 4-Dimensions of our coastal zone.

- Combined, subsidence and sea level rise challenge sustainability efforts across coastal Louisiana into the future.
Challenges from Sea Level Rise

Sea Level Change is not a new phenomena.

It has, and will continue to be a significant factor for Coastal Resiliency.
Challenges from Subsidence

• Subsidence has *and continues to be* the dominant *challenges* to maintaining vertical control along the Gulf Coast.

• Anthropogenic causes like forced drainage (*shallow*) and groundwater pumping (*deep*) appear to have the greatest impacts.

• The loss of elevation is making the coast more vulnerable to storm surge.
It has been found impractical to maintain with sufficient accuracy for reference purposes benchmarks, level heights, and tide gauges. Discrepancies in benchmarks and level heights and gauges could only be satisfactorily accounted for by the most plausible explanation of the subsidence of the whole delta, making gauges and benchmarks unreliable.
The National Geographic Magazine

AN ILLUSTRATED MONTHLY
Thank You

Questions??