“Subsidence and its effects on vertical control”

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Why do engineers and surveyors need to know about subsidence?

• Subsidence moves BMs away from the datum. Thus, subsidence affects your ability to access the National Spatial Reference System (NSRS). The benchmark you are using to base a design, to prepare a flood certificate, or establish the height of a levee, may no longer be valid.

• Subsidence over time changes the spatial relationship between terrestrial and water datums.

• Subsidence over time can submerge coastal lands, thus affecting land ownership.

• If not fully considered in the design, subsidence over time can compromise the effectiveness of flood protection.
Subsidence FAQ

- **What is it?**
  - “The downward movement of the Earth’s surface with respect to a datum.”
  - Subsidence has been misunderstood because of inaccurate measurement and false process assumptions.
  - It is a condition caused by any one or many natural and anthropogenic processes.

- **Where does it happen?**
  - All of south LA, MS, and TX. Subsidence is 4-D.

- **How fast does it occur?**
  - mm/yr to several dm/yr.
  - Subsidence rates are variable in time.
Global sea-level has been constant over the past 100 years.

Global sea-level has been slowing since the last glacial maximum.
Geodetic leveling shows that vertical motions vary in time and space.
Subsidence Derived from Geodetic Leveling
Southeast Texas

K. Shinkle and R. Dokka, in prep.
Natural and Anthropogenic Processes that Result in Subsidence

**Shallow Processes (processes above aquifers):**
- Natural consolidation and compaction: constant $\leq 3 \text{ mm/yr}$
- Human-induced consolidation and compaction*: $\sim 30 \text{ mm/yr}$
  - Desiccation by urbanization (behind levees)
  - Organic soil oxidation

**Deep Processes (processes below and including aquifers):**
- Sediment and water load induced flexure of the lithosphere*: constant $0$ to $-8 \text{ mm/yr}$
- Faulting: variable up to $-20 \text{ mm/yr}$
- Salt evacuation: variable $0$ to $-?? \text{ mm/yr}$
- Water pumping*: variable up to $-65 \text{ mm/yr}$
- Oil & gas extraction: variable $0$ to $-3 \text{ mm/yr}$

* The dominant causes of subsidence in LA
Natural Wetland

Disruption of Shallow Hydrology

Oxidization Organic Materials

Sediment oxidation, compaction and consolidation of organic materials:

\[ 0.1 \text{ – } 10 \text{ mm yr}^{-1} \]

- Flood Protection
- Forced Drainage

a Deveral & Rojstaczer, 1996
b Stephens & Speir, 1969
c Snowden et al., 1968
What does shallow subsidence look like?
Forced Drainage Speeds up Compaction

House built on piles (45ft) in 1964. The driveway, yard, and street have subsided over 2 ft (0.5 in/yr)
• Region above producing aquifers.
• Virtually all BMs and CORS are partially affected.
• Most people think all subsidence is caused by shallow subsidence.
Deep Rods and 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)
- "Stable" lower layer (only "deep" subsidence occur here)

2008 Ground Surface
- Point on casing adjacent to original position of the disk

Point of refusal

***This is a cross-section.
• Conventional wisdom has considered subsidence to be constant in time and space.
• Analysis of geodetic data as a function of depth shows that subsidence is variable in time and space (vertical and horizontal).
• Thus, to measure subsidence, you need to understand what the underlying processes might be so that a proper measurement strategy can be designed.
• It is all about the monumentation!
Monumentation determines how much of the subsidence you measure.
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Tectonic loading explains well deep subsidence recorded by CORS and Water Level Gauges.

- Freshwater Bayou: -3 mm/yr
- Grand Isle: -6 mm/yr
- Rigoletts: -3.7 mm/yr

Ivins, Dokka, & Blom (2007)
Geodetic Measurements Show that Subsidence Varies in Time and Space

A Regional Subsidence Profile Based on 1970’s Leveling

- **Grand Isle**: footprint of delta
- **Kenner**: moderate subsidence
- **Gretna**: slight subsidence
- **New Orleans East**: severe subsidence
- **Pensacola**: stable

Vertical Velocity (mm/yr)

1 in/yr
Analysis of National Geodetic Survey 1st Order Level Data

- 1955-1995
- All monuments set below Holocene.
- No Holocene effects!!
- There is a lot of subsidence occurring below the Holocene.
- It’s not just compaction.

Let’s test the results with water level gauges.
Gauges mounted on piles supporting bridges that penetrate well below Holocene sediments

NO SHALLOW SUBSIDENCE!!
The cone of depression?
-80
-70
-60
-50
-40
-30
-20
-10
0
Vertical Displacement 1991-1995 (mm)
North
South
High yield water wells
Paris Road Bridge
cone of depression?
SB 008B
SB 008B
SB 012B
SB 012B
SB 014B
SB 014B
G 189 RESET
G 189 RESET
Z 297
Z 297
Z 297
Z 297
J 278
J 278
D 374
D 374
V 371
V 371
T 387
T 387
Total Displacements
Distance from Benchmark 236 AZ MK (km)

Consistent with groundwater pumping

I-610 Bridge: Subsided ~1 m in 35 years
Why the Louisiana Coast is Being Lost

Sediment Accretion = \[ \text{Global Sea-level Rise} + \text{Local/regional effects} + \text{Subsidence} \]

Global Sea-level Rise = 2-3 mm/yr

Local/regional effects = negligible

Subsidence = varies in time and space

Sediment Accretion = \[ \text{terrigenous (river)} + \text{organic (in situ)} \]
Let’s Predict the Future!

Using the recent past as our guide to the near future.

Subsidence due to tectonic loading, natural compaction, and levee building. Let’s assume that we stop groundwater pumping and the faults stop slipping.
Flood Protection

Levees

- Approximately 1,500 km of levee structures currently cross the Louisiana Coastal Zone.
- An additional 200 km of levee is proposed for the Morganza and Donaldsonville to the Gulf projects.
Constrained Wetlands, Natural Wetlands, and Natural Levees.
2010 DEM Elevations

- Approximately 897 miles (2.3 million km²)

Coastal Louisiana 2010: Land Elevations

- High: 49.9 m
- Low: -45.4 m
2100

27.1% Land Area at or below Sea Level

Approximately 2,724 miles (7 million km²)
Percent Land Below Sea Level by Parish Through 2100

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Conclusions

- Subsidence has and continues to be the dominant challenge to maintaining horizontal and vertical control along the Gulf Coast.
- Anthropogenic causes like groundwater pumping and forced drainage dominate subsidence.
- The loss of elevation is making the coast more vulnerable to storms.
Thank You!