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How Can We Most Efficiently Use Our Limited Water, Sand, & $? Diversions to Build Land in the Mississippi Delta

Benjamin F. Hobbs, Melissa A. Kenney

Environment, Energy, Sustainability & Health Institution, The Johns Hopkins University

David Mohrig *University of Texas*

Gary Parker *University of Illinois*

With thanks to Wonsuck Kim (U. Texas), Hongtai Huang (JHU), Jeffrey Nittrouer (Rice U.), Chris Paola (U. Minn.), Robert Twilley (LSU)

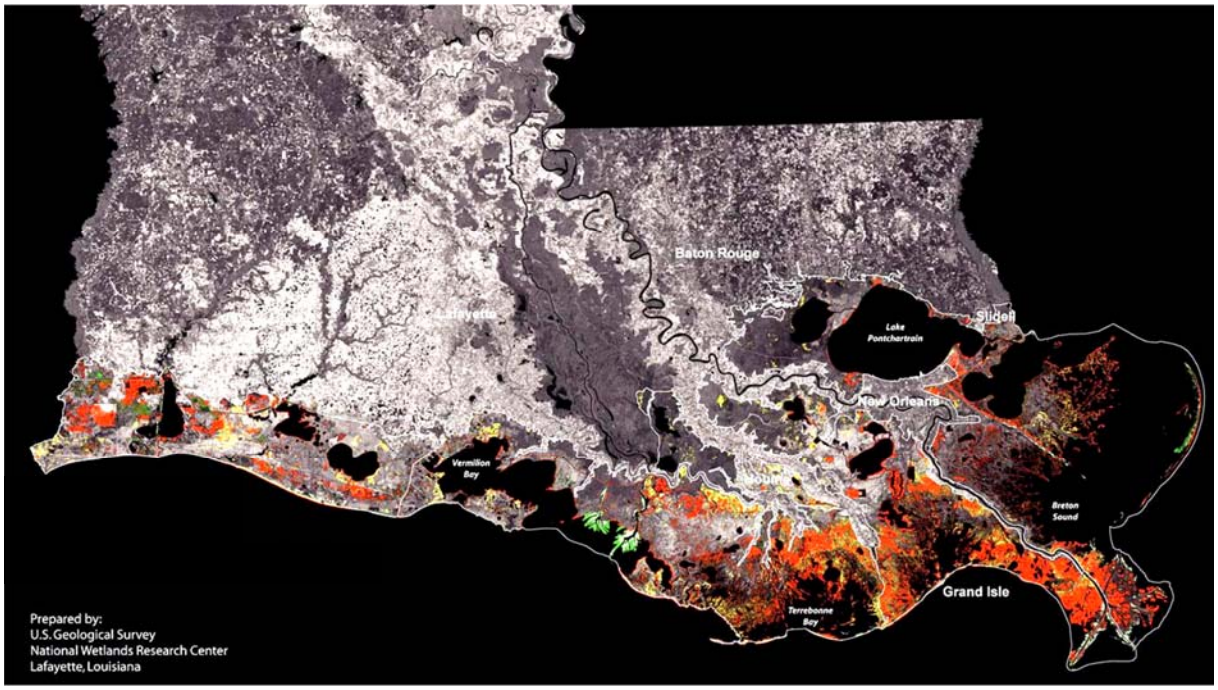
ASCE EWRI, 20 May 2013

WRR (in press)

Outline

- **Motivation**
- **Drivers**
  - **More sand at depth**
  - **Scale effects in construction cost, land building**
- **Optimization**
- **Results**

Motivation: Land loss in lower delta since 1932



"Beset by land subsidence and rising sea levels, much of this vast area will inexorably sink beneath the waters by the end of this century."

- Bruce Babbitt, *Washington Post*, 5/18/2007

Sediment lost to the deep Gulf

Knowledge.allianz.com

Degraded barrier islands

www.clear.lsu.edu/needs_in_louisiana

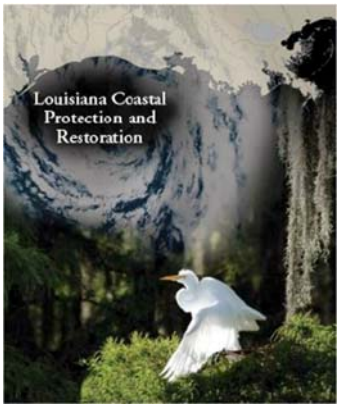
Loss of wetlands

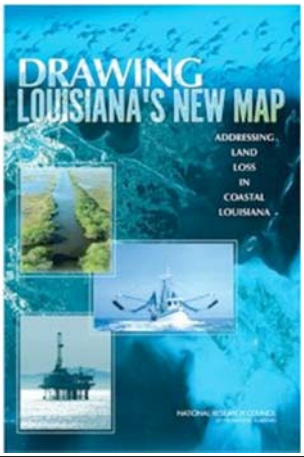
coastalcare.org/2012/03/sea-level-rise-subsidence-and-wetland-loss

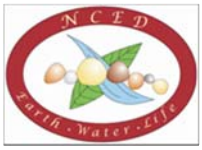
Loss of swamps

www.american-buddha.com/drownorleans3a.jpg

There are many proposed solutions… land building is critical to achieving most objectives







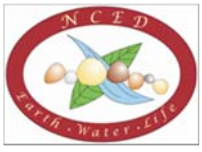
What portfolio of diversions gives the biggest land bang for our buck?

(Turner & Boyd, "Mississippi River Diversions, Coastal Wetland Creation/Restoration, & an Economy of Scale," *Ecol. Engin.*, 1997)

Deep *vs.* Shallow? Narrow *vs.* Wide?

Old River Control Structure

West Bay



Source: http://en.wikipedia.org/wiki/File:Old_River_Control_Structure_Complex.jpg
http://www.mvn.usace.army.mil/prj/westbay/photos/West-Bay-Sediment.gif

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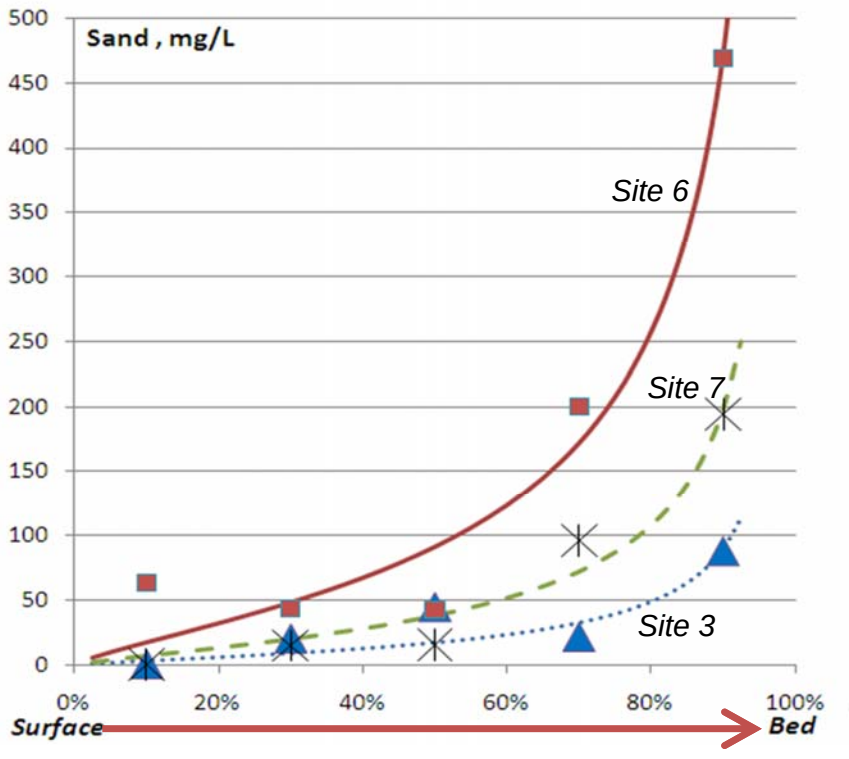
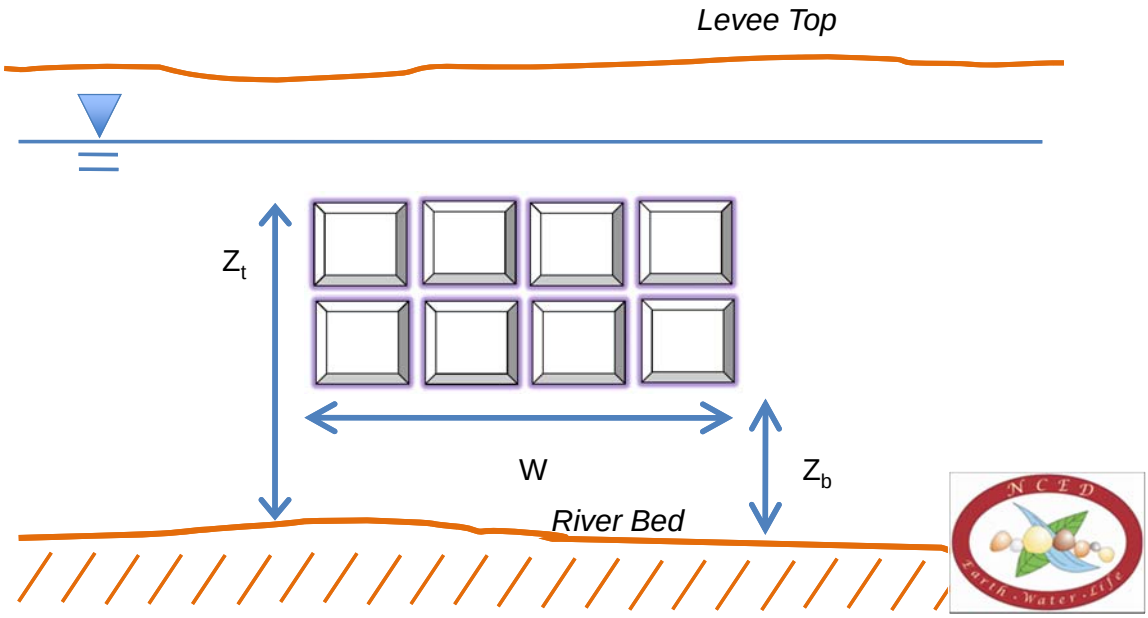
More sand deeper in the water column



Data source: Nittrouer, J.A., D. Mohrig, and M. Allison, 2011, Punctuated sand transport in the lowermost Mississippi River, *Journal of Geophysical Research*, Vol. 116, F04025

More sand at depth + water limits
→ Important design questions (*where*, *how deep & wide*)

Multi-Box Culvert Diversion

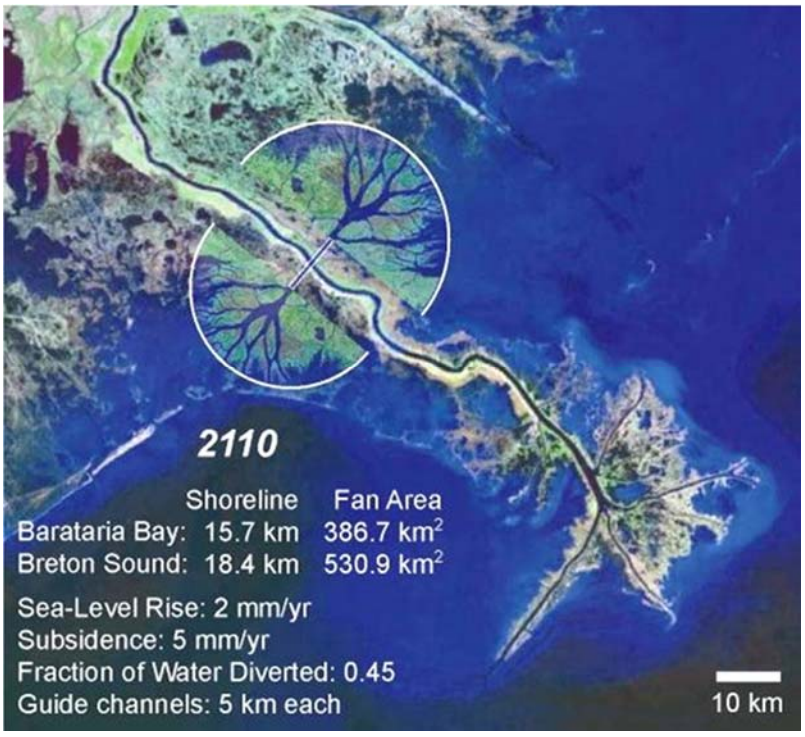


Dynamic Delta

$$\left(\dot{H}+\sigma\right)A_{top} = f_r Q_s + r_{org} A_{top}$$

Δ Delta Area determined by difference between:

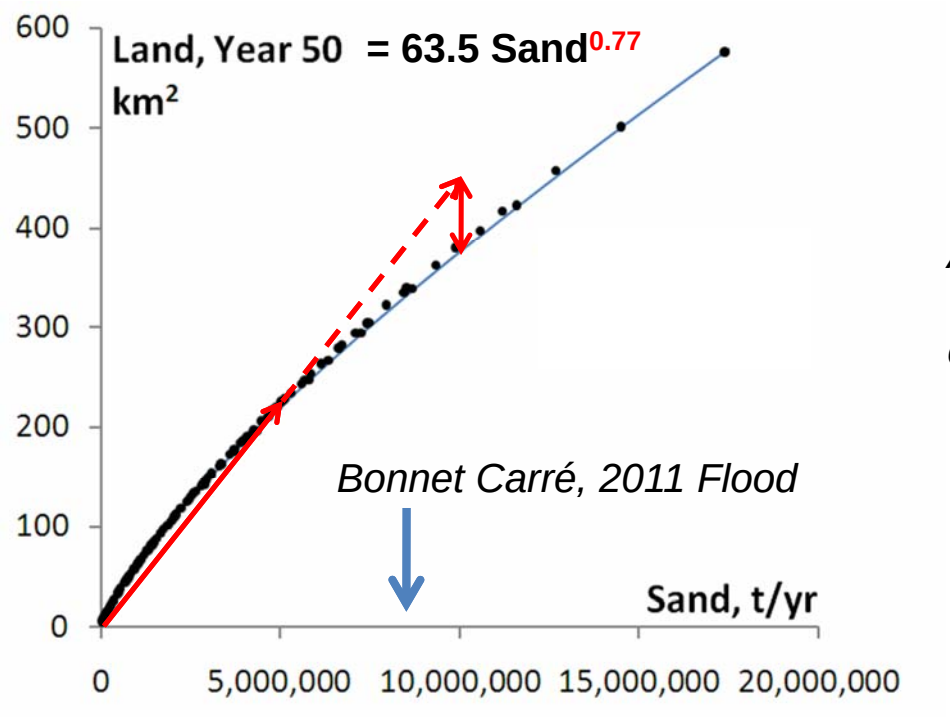
{Sea-level rise, Subsidence}
&
{Deposited sediment, Accumulated organic matter}



Results of Land building Model : Base Case
(Parker, Kim, Mohrig, Paola & Twilley, AAAS 2008)

Bathymetry & sand capture efficiency:

→Single project: scale diseconomies in land building as *f*(sand)



Assumes 75 days/yr of diversions

Cost of Existing Diversions

(not built or managed to maximize land building)

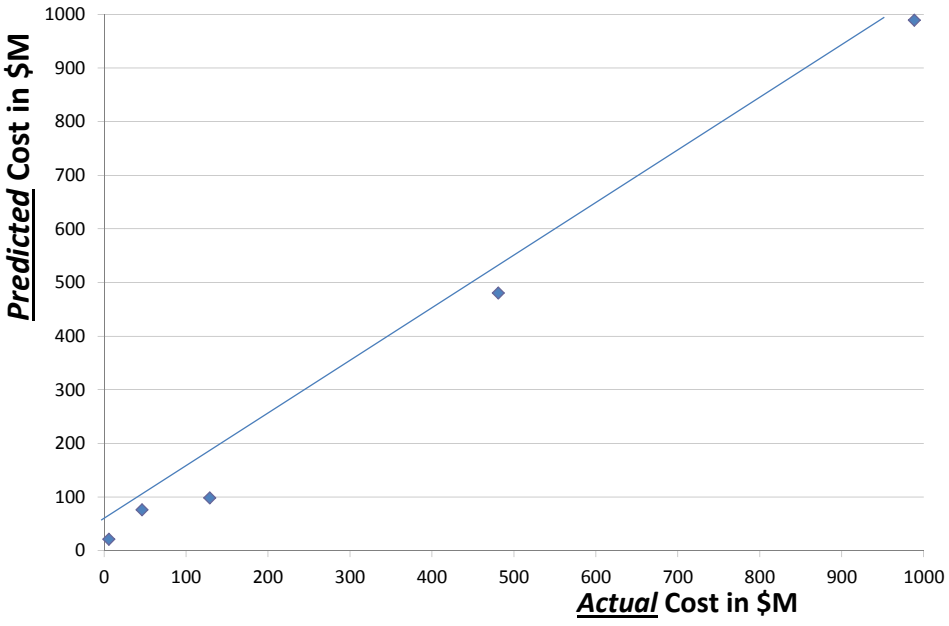
	Depth (m)	Width (m)	Cost (2010$)
Bonnet Carré	7.62	2330	$481M
Caernarvon Diversion	7.32	57	$46M
Davis Pond	7.92	74	$129M
Old River Control Structure	19.51	425	$989M
West Bay	2.44	170	$5.92M

Cf. largest diversions in La Coastal Protection & Restoration Authority 2012 *Master Plan*:

- $0.6-1.1B
- Divert 250,000 cfs
- Build 75-280 km² of land in 42 years

Cost (2010$M) = 0.43Depth$^{1.6}$ Width$^{.48}$

Scale diseconomies in Depth; economies in Width



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Optimization Model

"Multiobjective Backpack Problem"

Let: n_i = # projects of type i (differ in width, depth, aperture height)

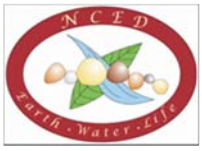
C_i, L_i, W_i = Project i's: \$ cost; km^2 land after 50 yrs; m^3/s water diverted

$$\underset{\{n_i, i \in I\}}{\text{MIN}} \; COST = \sum_{i \in I} C_i n_i$$

subject to:

$$n_i \in \{0, 1, 2, \ldots\}, \forall i$$

Solving this yields a *portfolio* $\{n_i, \forall i\}$ that is *efficient* in terms of the objectives *COST*, *LAND*, *WATER*



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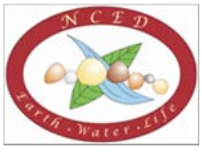
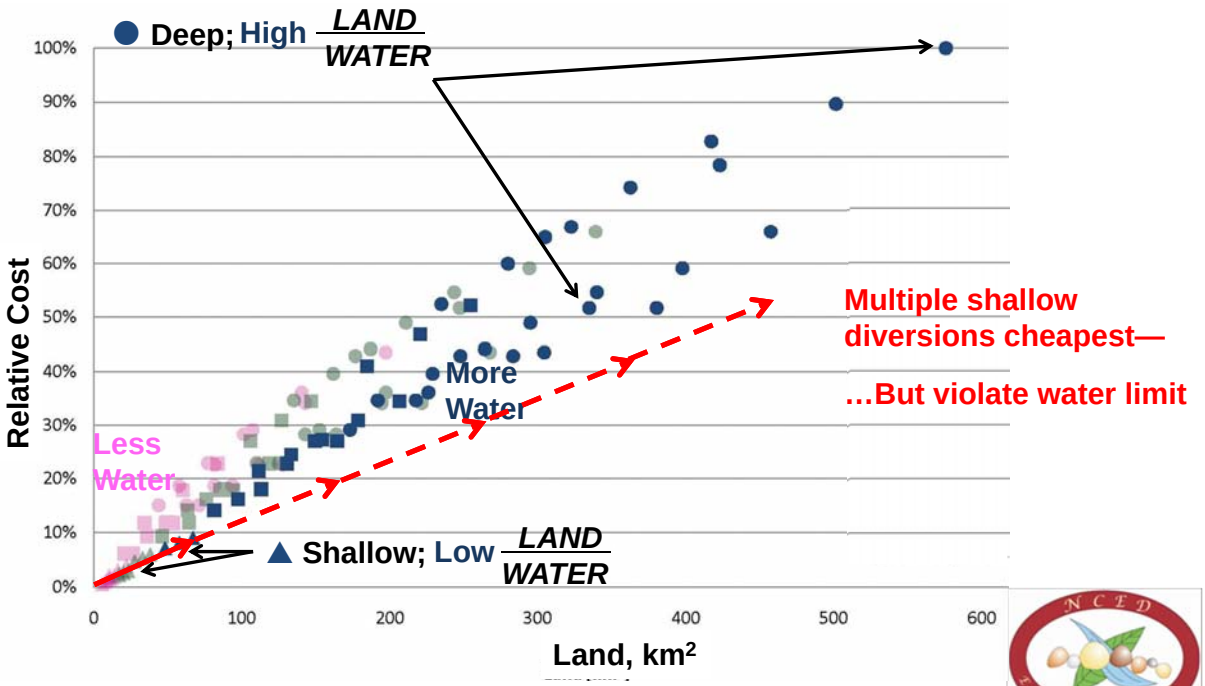


Single Projects: Cost & Land Yr 50

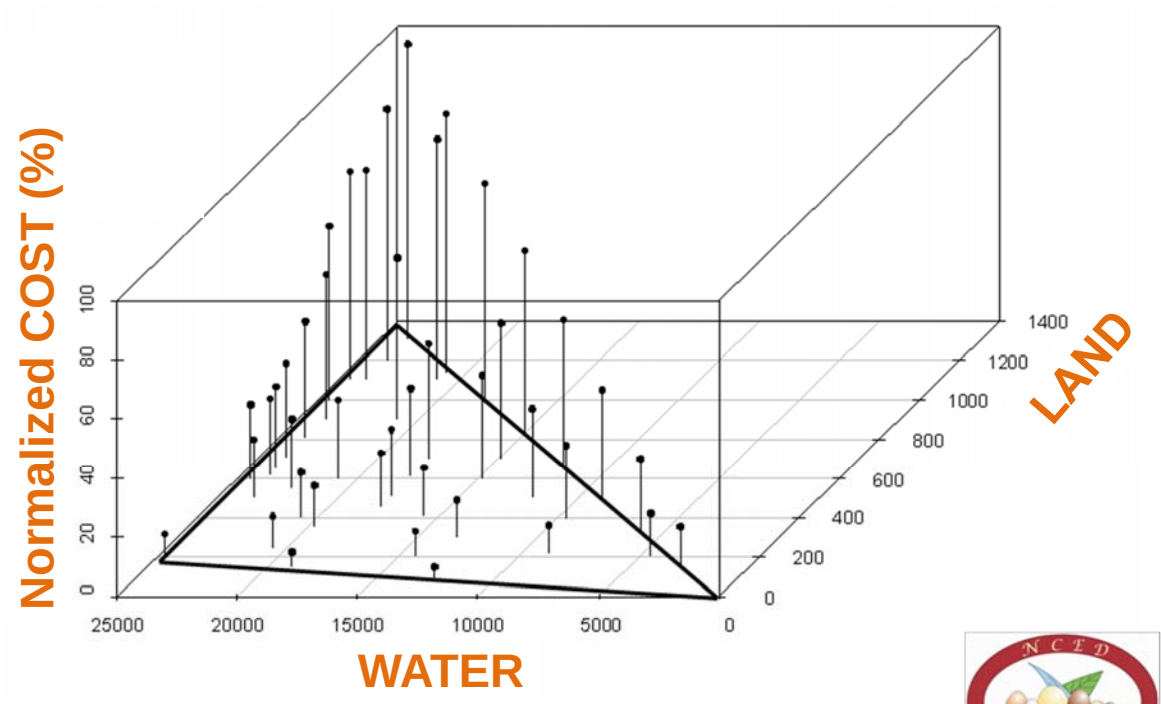
Given: Scale diseconomies (Depth), economies (Width)



→ ***We must go deep to meet larger land targets***

Efficient Project Portfolios

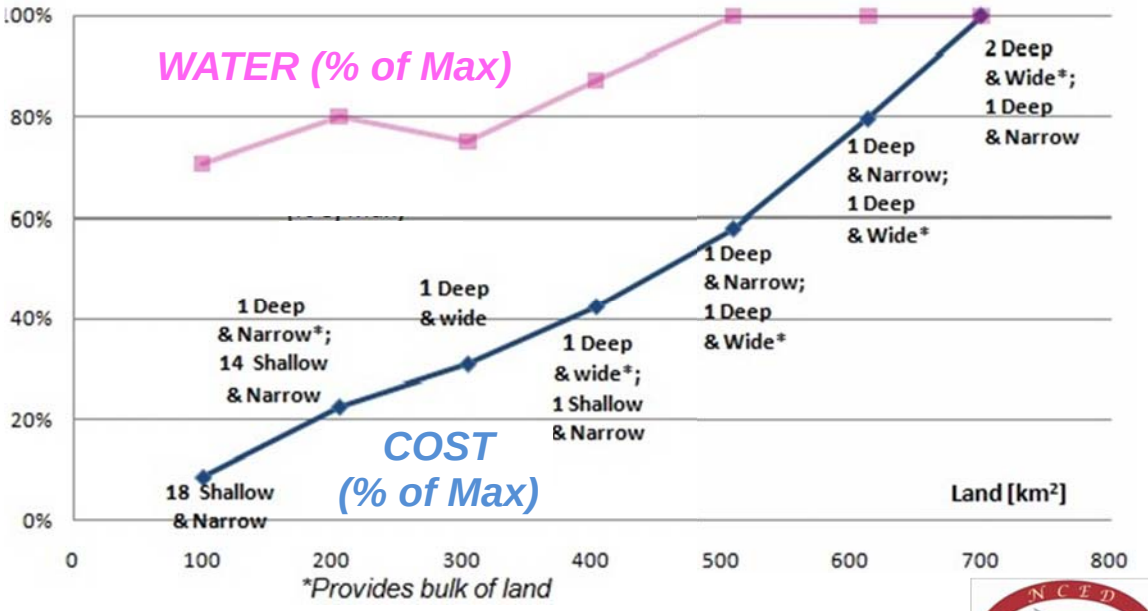
Given: Scale diseconomies (Depth), economies (Width)



$COST \approx LAND^{1.4} WATER^{-0.5}$, $R^2 = 0.98$

Tradeoffs Among Portfolios

Given: 18,000 m^3/s water limit during 75 day flood season;
Scale diseconomies (Depth), economies (Width)



But if no cost scale effects → build more, narrower projects

Summary

- **Model**
  - Land = $L(H_2O, \text{sediment}, t)$
  - Cost = C(diversion depth, width)
- **Must balance scale tradeoffs:**
  - *Scale economies:*
    - Wider: cheaper per unit of sand
    - Deeper: more sand per unit of water
  - *Scale diseconomies:*
    - Deeper: more costly per unit depth
    - Sand yields diminishing returns in land
- **To get the most land for your $, almost all portfolios include one or more deep projects**
  - Due to water constraint
  - Several projects best if width economies are weak

"Because [sediment diversions] are so effective, it is no longer a question of whether we will do large scale diversions but how we will do them"

(LaCPRA Master Plan, 2012, emphasis added)

Caveats

- **Generic cost, sediment, & land functions, not site-specific conditions**
  - *CPRA Master Plan is site specific*
  - *But theory shows: larger diversions most efficient*
  - *Need more work a la CLEAR (R. Twilley et al.) and C. Willson et al.* ("Physical & Numerical Modeling of River & Sediment Diversions in the Lower Mississippi River Delta", Coastal Sediment Processes '07, ASCE)
- **Our only objectives: cost, land, water**
  - *Yet not all "land" equal ecologically, socially, or for surge protection*
  - *If large projects have disproportionate negative social/environmental effects*
    → *might prefer to build less land, spend more money*
- **Can we design structures to divert more sand? Investigation needed**
  - *Bonnet Carré sediment experience*

CAN WE REALLY DIVERT LARGE QUANTITIES OF SAND?

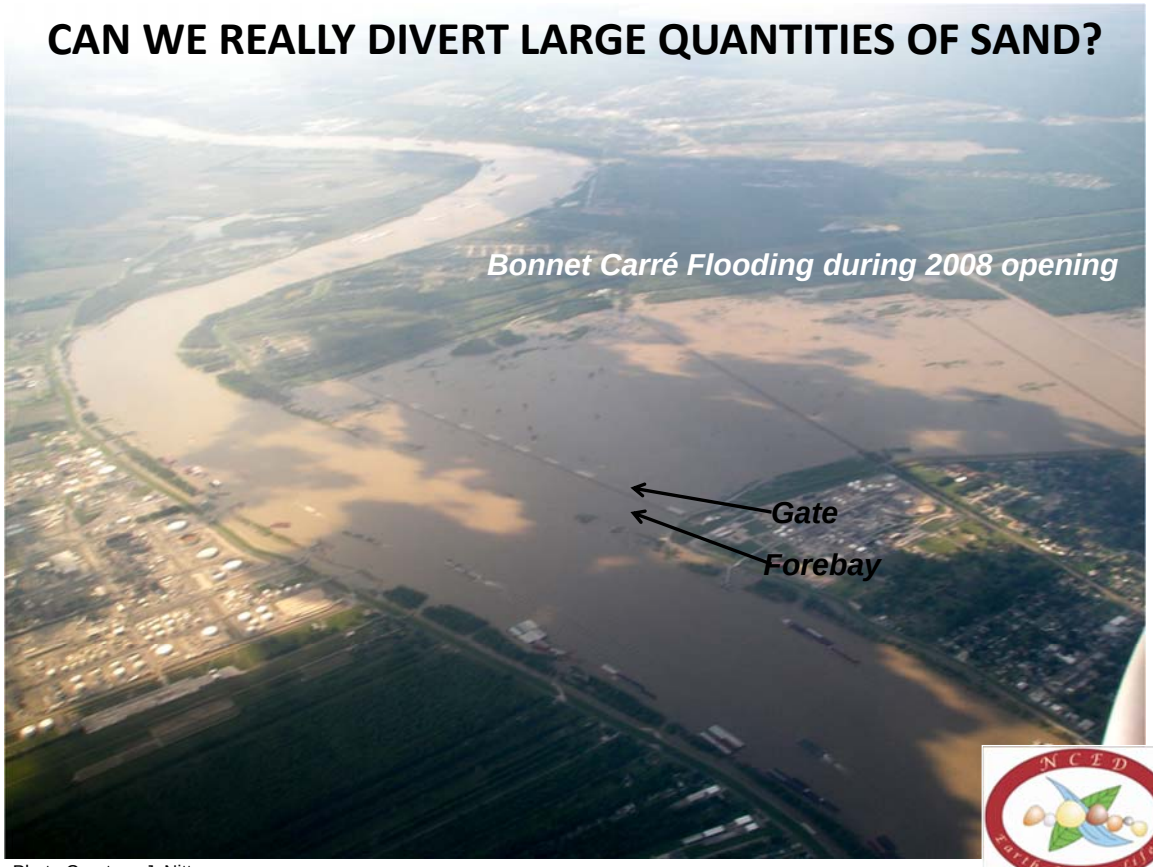


Photo Courtesy J. Nittrouer

Inadvertent test: Bonnet Carré Spillway, flood of spring 2011

(Survey by J. Nittrouer et al., *Nature Geosciences, 2012*)

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Thank you!

B.F. Hobbs, bhobbs@jhu.edu