Middlebury Institute of International Studies at Monterey: The Challenge of the World's Deltas

Christopher F. D'Elia, Ph.D.
Professor and Dean
College of the Coast and Environment
Louisiana State University
Baton Rouge, Louisiana 70803 USA

LSU | College of the Coast & Environment

What I Want to Cover Today

- The generic challenges of coasts and deltas
- What the term “sea level” means
- What causes deltas to accrete or erode
- The scope of the delta problem world-wide
- The delta problem in the US, with special reference to Louisiana
- Examples of other deltas in trouble
- What are we doing, and what possible pitfalls exist?

Healthy Coastal and Ocean Resources: The Ocean Economy is Critical to U.S.

- Contributed $352+ billion to the U.S. GDP
- Supported 3.1 million jobs (2014)
- Carried $1.5 trillion of cargo through U.S. seaports (2016)
- Generated $3.5 billion in revenue from oil and gas leases to the U.S. Treasury (2017)

https://oceanservice.noaa.gov/facts/oceaneconomy.html

The Coastal "Triple Whammy"

From the Atmosphere

Climatic and Meteorological Factors

From the Land

Sediments ↓
Nutrients ↑

Coastal Challenges:

- Relative sea level rise
- Eutrophication
- Land-use changes
- Ecosystem changes
- Demography

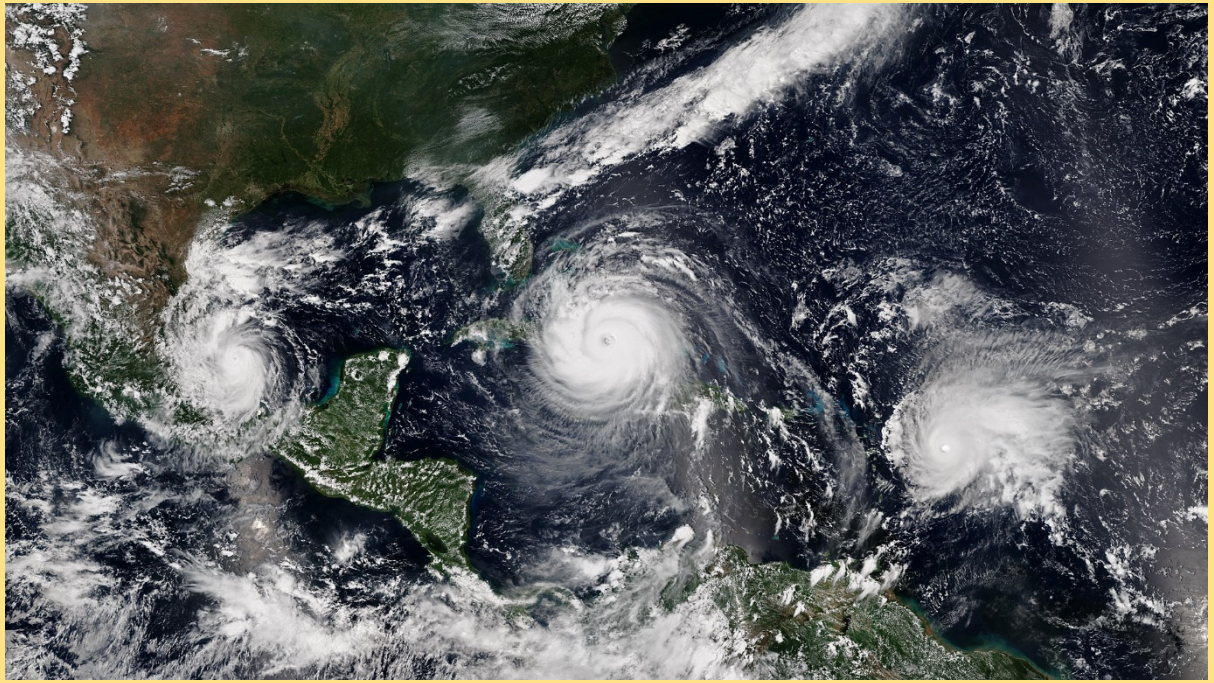
From the Sea

Eustatic sea level ↑
Severe storms ↑

Coastal scientists recognize that coastal systems are highly susceptible to change

Vulnerability of Coastal Communities

- Presently ~40% of the world's population lives within 100 kilometers of the coast.
- A large part of our nation's economic productivity is located in coastal zones.
- Sea level-rise can threaten the long-term operation of drinking water, wastewater and storm water utilities.
- Rising sea levels can introduce new, or exacerbate existing, saltwater intrusion into freshwater resources. Both groundwater and surface water sources are at risk.
- A three-foot sea level rise would result in a loss of wastewater treatment services for 8.4 million Americans.



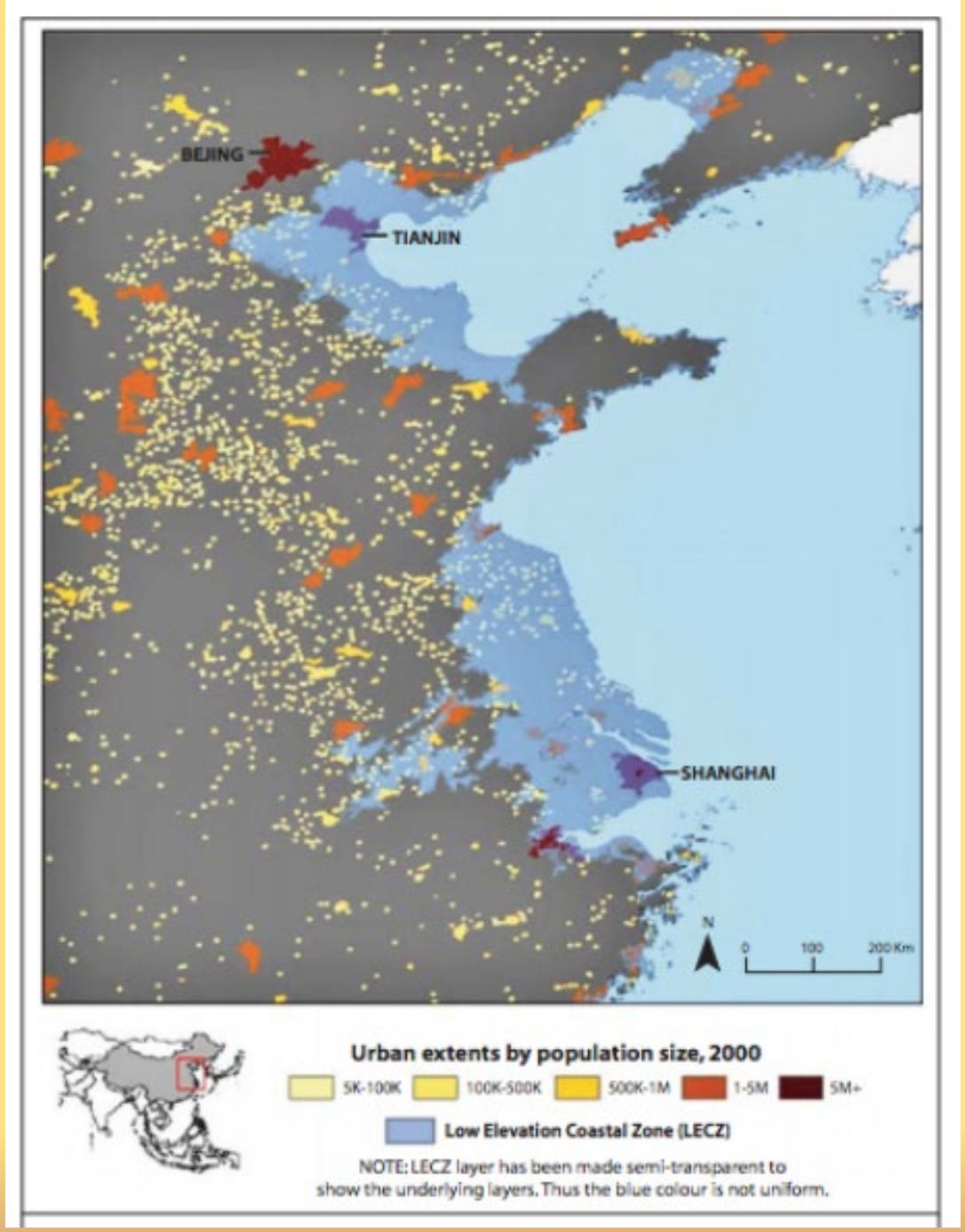
Hurricanes are predicted to become more intense and frequent in the future

image captured by the National Oceanic and Atmospheric Administration's Suomi NPP satellite - NOAA View Global Data Explorer

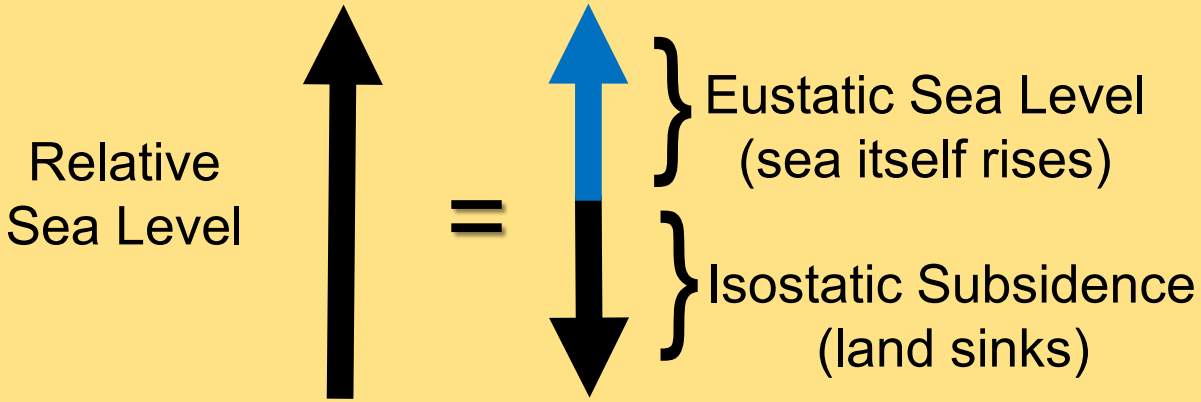
Coastal Demographic Trends in 2007

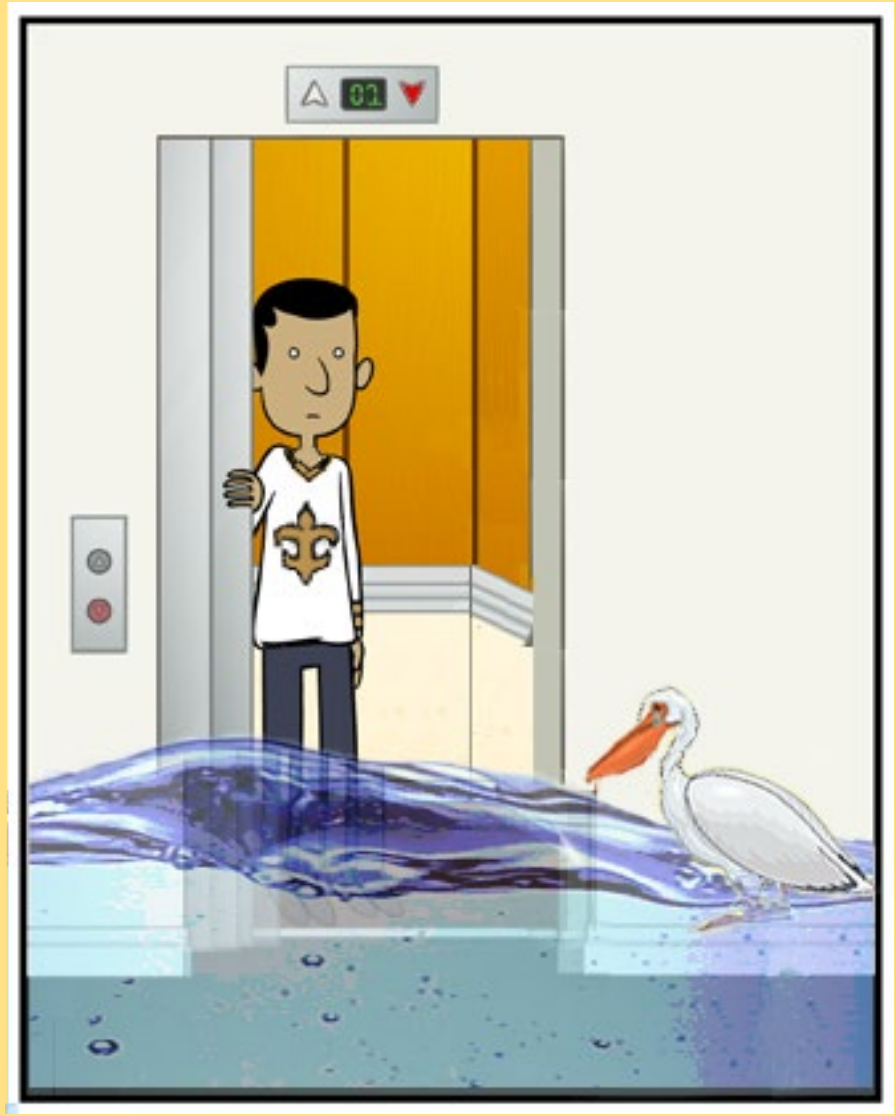
- Globally about 630 million people live below 10m (above sea level)
- 11 of 15 the world's cities of >10 million are situated below 10m
- 340 million people are living in urban areas below 10m
- China alone has 143 million people living in areas below 10m (11% of the total population)
- China had 78 million people living in urban areas below 10m
- ***It's only gotten worse since 2007***

Source: CUNY. 2007. International Institute of Environment and Development.



Components of Relative Sea Level Rise





It's like standing in an elevator going down while the water in and around the building is rising

Climate Change and Eustatic Sea Level Rise

- Climate changes – it always has; it always will
- Evidence is strong that burning of fossil fuels and CO_2 emissions exacerbate global warming to cause the sea to rise by thermal expansion
- The cause notwithstanding, anthropogenic or not, plenty of evidence exists that eustatic sea level rise is occurring, but subsidence has been a larger problem in the past
- Coastal interests must adapt to these realities

EUSTATIC SEA LEVEL RISE IS ACCELERATING…

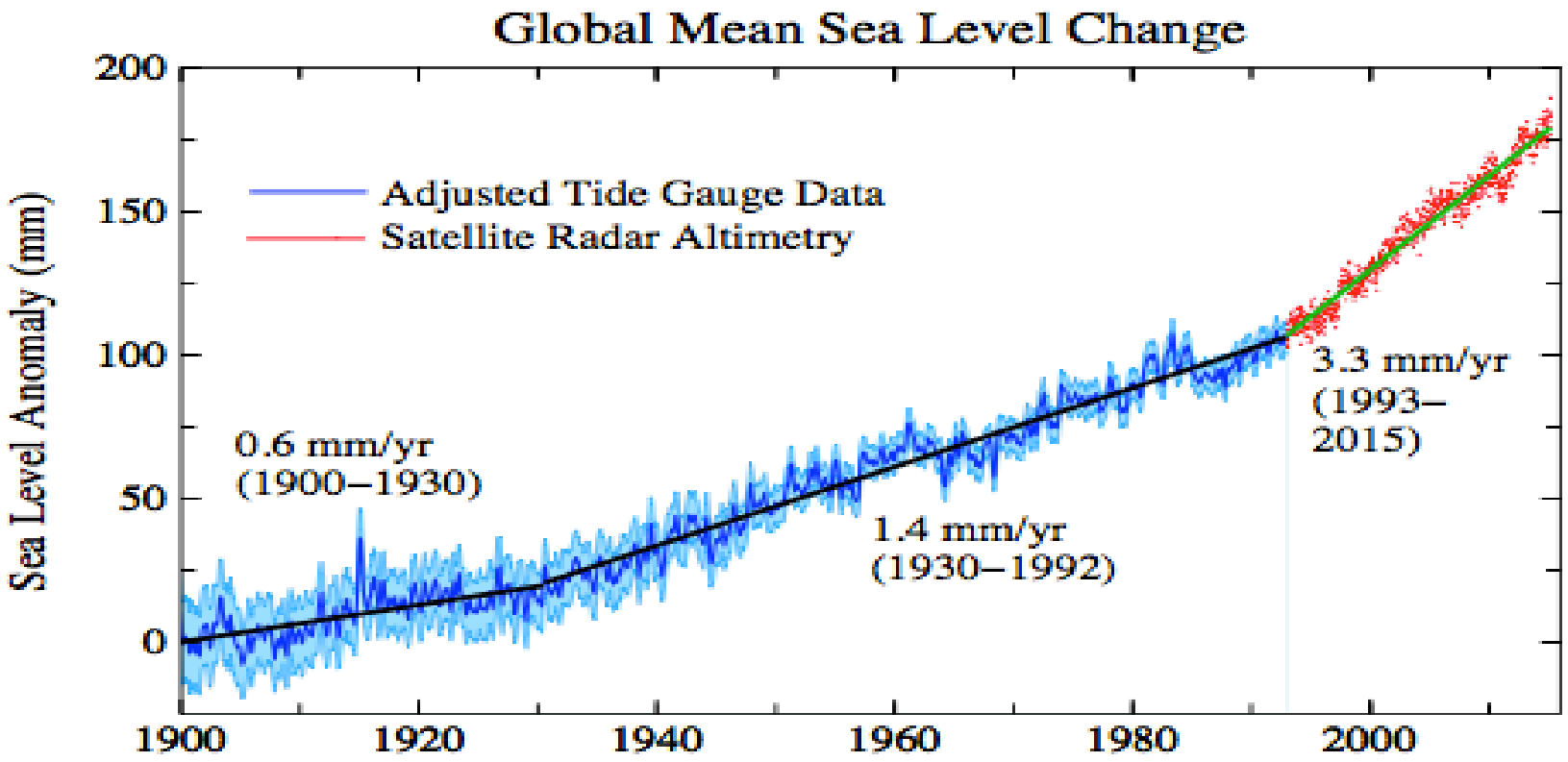
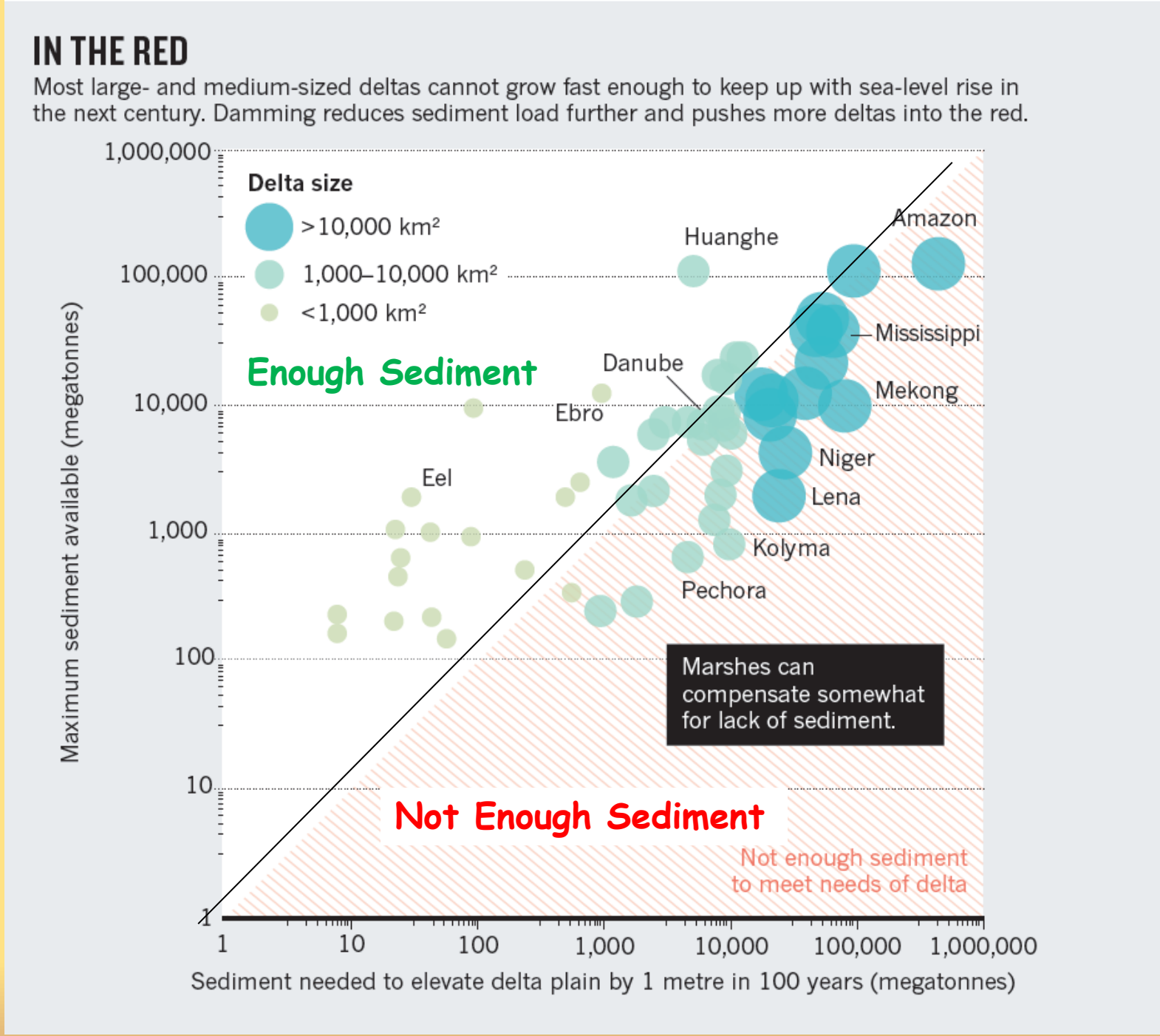


Figure 29. Sea level change based on satellite altimetry data (Nerem et al., 2010, updated at http://sealevel.colorado.edu) and tide gauge data (Church and White, 2011) with the latter change rate multiplied by 0.78, as required to yield a mean 1901–1990 change rate 1.2 mm yr^{-1} (Hay et al., 2015).

From Hansen et al. 2015

Counteracting Sea Level Rise and Subsidence:

Sediment Input Deficiency Concerns Relate Directly to Human Engineering of the Natural Hydrologic System



Source: Giosan et al. 2014

Deltas at risk (From IGBP/LOICZ) By numbers

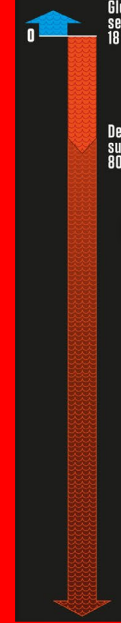
Deltas have long shaped humans' lives: our ancestors thrived in river valleys like the Nile, Indus and Yellow. Their rich topsoil, refreshed every year by floods, fed and sustained our early societies.

Today, the story is reversed: humans are shaping deltas. And some deltas are no longer thriving. Modern humans extract oil and water from delta sediments and the rocks below; they build dams upstream that trap sediments that would have replenished the deltas. These and other human activities have led to compacted soils – and slowly sinking deltas.

1%	The amount of Earth's land area occupied by deltas.
24	The number of major deltas that are sinking.
4m	Between 1974 and 2010 some parts of Jakarta sank over four metres.
45-82cm	The likely range of global average sea-level rise possible by 2100 if emissions continue unabated. Sea level will continue to rise beyond 2100.
85%	The percentage of major deltas that experienced severe flooding in the last decade.
>500 million	The number of people who live on deltas.

Sea-level rise vs. delta subsidence

(20th century change)



Delta risk map

SUBSTANTIAL RISK
Sediment deposition rates less than sea-level rise

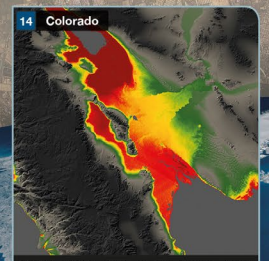
1 Paraná, Argentina
2 Vistula, Poland
3 Indus, Pakistan
4 Brahmani, India
5 Mahanadi, India
6 Godavari, India

GREATER RISK
Ground compaction exacerbating low sediment deposition rates

7 Mississippi, United States of America
8 Magdalena, Colombia
9 Niger, Nigeria
10 Tigris, Iraq
11 Ganges-Brahmaputra, Bangladesh
12 Irrawaddy, Myanmar
13 Mekong, Vietnam

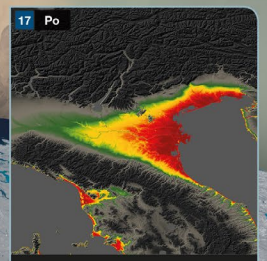
SEVERE RISK
Virtually no sediment deposition and accelerating compaction

14 Colorado, Mexico
15 São Francisco, Brazil
16 Rhône, France
17 Po, Italy
18 Nile, Egypt
19 Krishna, India
20 Yellow, China
21 Yangtze, China
22 Pearl, China
23 Chao Phraya, Thailand
24 Tone, Japan



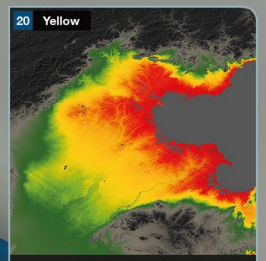
14 Colorado

After farms and urban areas have taken their water allotments, the Colorado River slows to a trickle by the time it reaches its delta. Sometimes it stops flowing altogether and then no sediment is deposited.



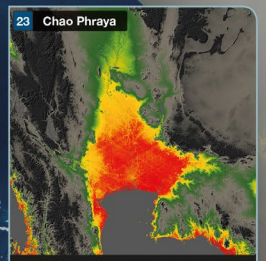
17 Po

The Po delta experienced a 6cm annual subsidence rate, due to sea-level rise and methane extraction. This reduced dramatically once methane extraction ended.



20 Yellow

As deltas sink the risk of flooding rises. In the Yellow River delta typhoons have caused 5m-high storm surges.

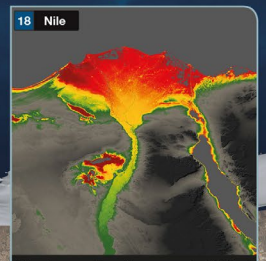


23 Chao Phraya

In 2011, the Chao Phraya river flooded swamping Bangkok and leaving much of the capital submerged for months. The city has been sinking for decades due to groundwater extraction. Steep taxes on groundwater have slowed subsidence substantially.

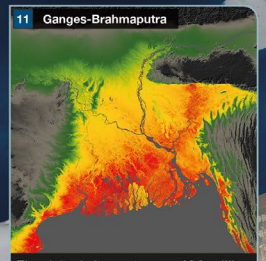
Amazon

Despite forest destruction, hydro-electric dam projects and more impacts upstream, the Amazon River delta is in relatively good health. Nearly 3 million people live on the delta but its sheer size dampens human impacts.



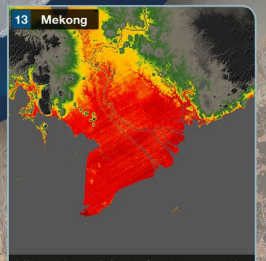
18 Nile

The Aswan Dam traps nearly 98% of sediment flow downstream. Without those soils, the Nile Delta has compacted and sunk. Relative sea-level rise there is 4.8 millimetres every year.



11 Ganges-Brahmaputra

The delta is home to over 100 million people making it the most populated on Earth. Effective sea-level rise is up to 18 millimetres per year. In 2007–08, substantial flooding affected the Ganges, Mekong, Irrawaddy, Chao Phraya, Brahmani, Mahanadi, Krishna and Godavari. More than 100,000 died and more than a million people were displaced.



13 Mekong

Like other deltas, farmers on the Mekong have cut down mangroves to create space for shrimp ponds. Surveys indicate roughly half the mangrove forests have disappeared. Mangroves help prevent erosion and are important flood defences.

ELEVATION (metres)

-3 3 6 10 20 30 40 100 500

SOURCES

Syvitski J P M *et al.* (2009) *Nature Geoscience* 2: 681-686. doi:10.1038/ngeo629

Ericson J P *et al.* (2006) *Global and Planetary Change* 50: 63-82. doi:10.1016/j.gloplacha.2005.07.004

IPCC (2013) Summary for Policy Makers. In: Stocker T F *et al.* (eds) *Climate Change 2013: The physical science basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA. www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf

Elevation Data: NASA Shuttle Radar Topography Mission Global 3 arc second V003

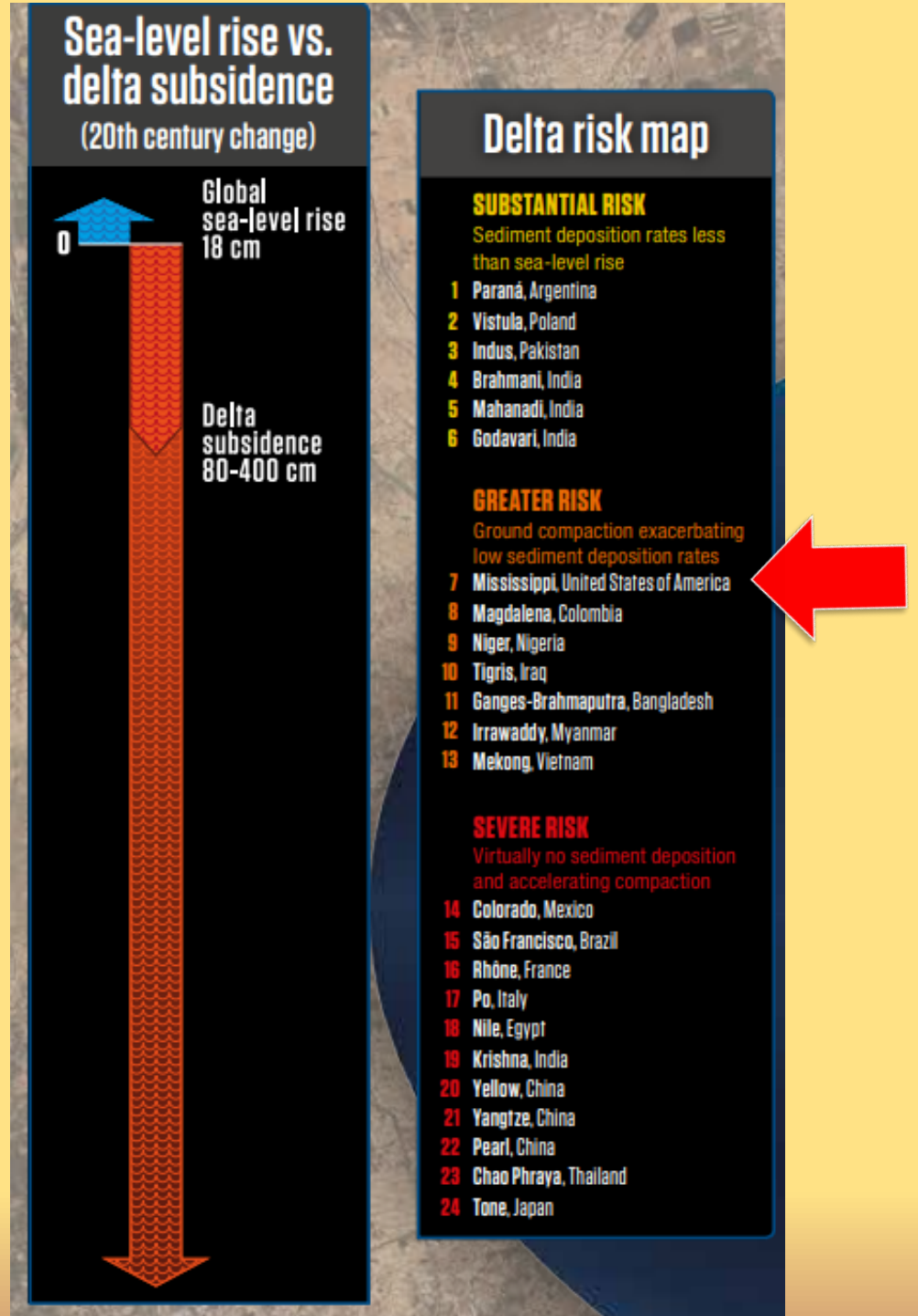
Cartography and design: Globaïa

GLOBAL IGBP CHANGE International Geosphere-Biosphere Programme

This infographic was produced by the International Geosphere-Biosphere Programme.

Expanded from previous slide:

- Eustatic sea level rise is much less a factor than subsidence
- In terms of delta risk, the Mississippi Delta, despite its problems, is not even in the severe risk category
- The severe risk category includes deltas with large population centers and with important cultural assets like Venice in the Po Delta and the Nile Delta.



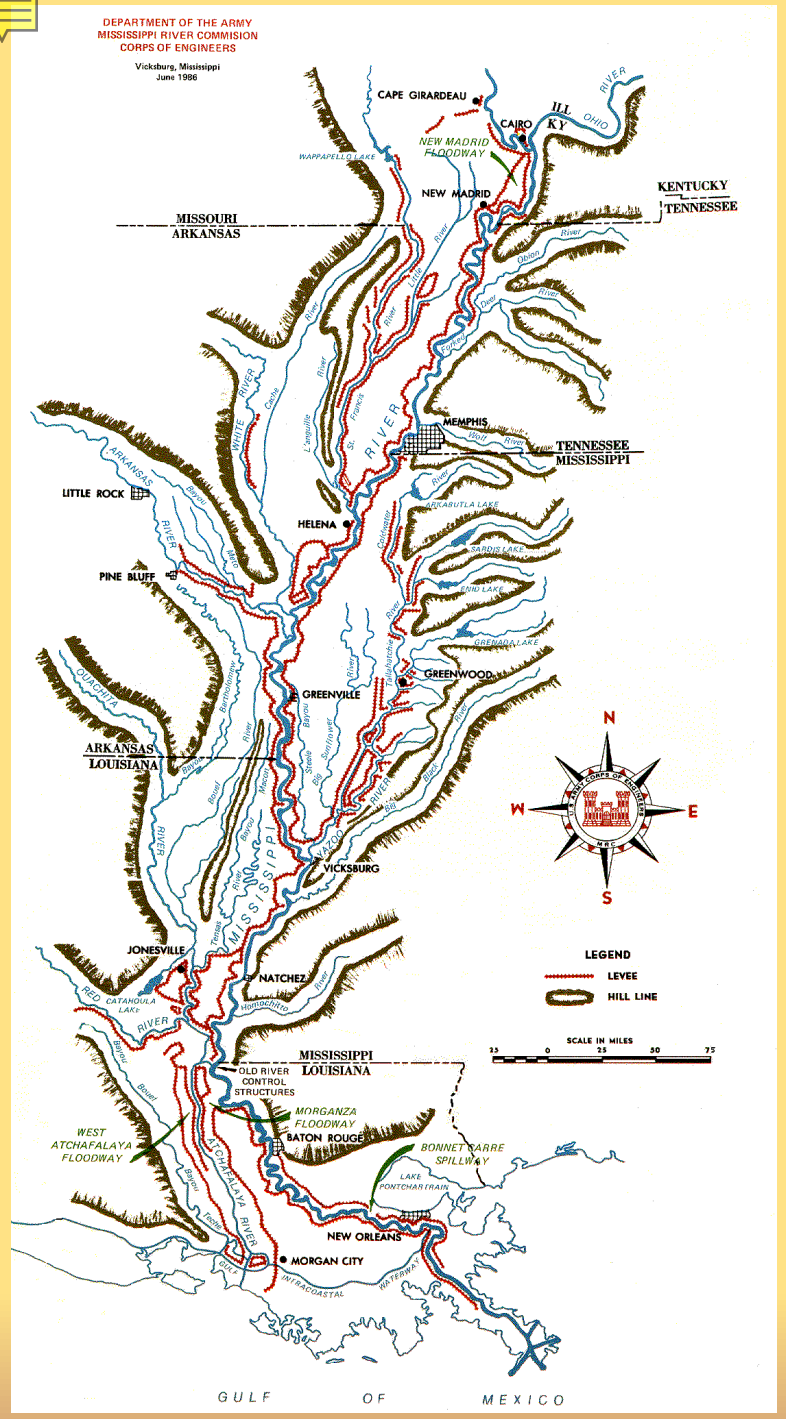
Human Alteration of Natural Waters

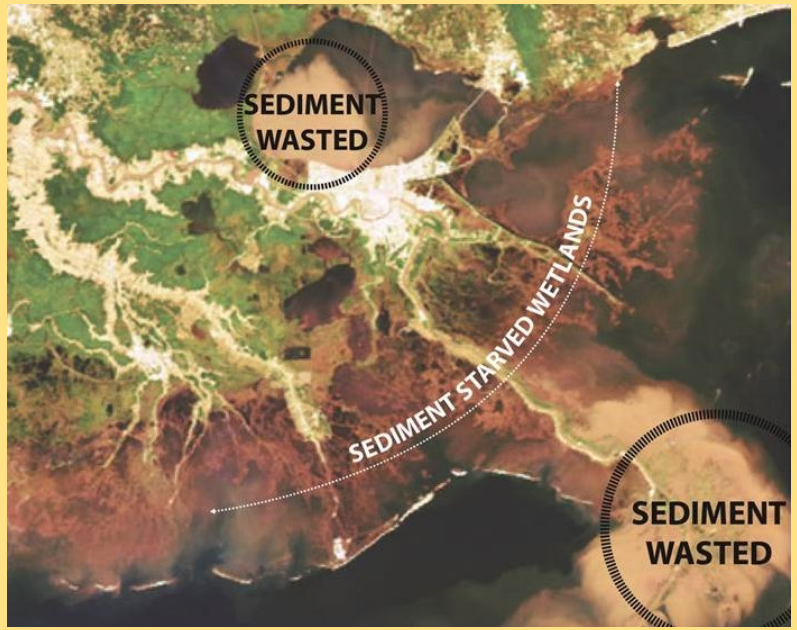
- Human activities are of major importance
  - ❖ Build dams, levees, dikes, canals, etc.
  - ❖ Enhance deforestation and agriculture
  - ❖ Irrigate
  - ❖ Construct pavement; urbanize
- Water control structures have tripled water residence time in impoundments and reduced water held in upland sediments
- The damming of the world's rivers is pervasive (>50,000 large dams now span the watersheds on 6 continents).
- Humans now use about 17% of global river volume
- Reservoirs intercept more than 40% of global river discharge (and perhaps 1/3rd of sediments, too)
- This is also Global Change!

Value and Risks: World's Deltas

- The World Delta Database lists about 75 deltas world-wide; many are at risk
- 24 out of the world's 33 major deltas are sinking and 85% have experienced severe flooding in recent years
- Good places to locate cities: more than 500 million people (1 of every 14 humans) worldwide live on deltas, many in sprawling megacities such as Shanghai, Dhaka and Bangkok
- High economic value (trillions of dollars)
- Very rich soils, excellent farmland
- Good transportation access to inland areas
- Areas for fossil fuel development

The Mississippi River Levee System

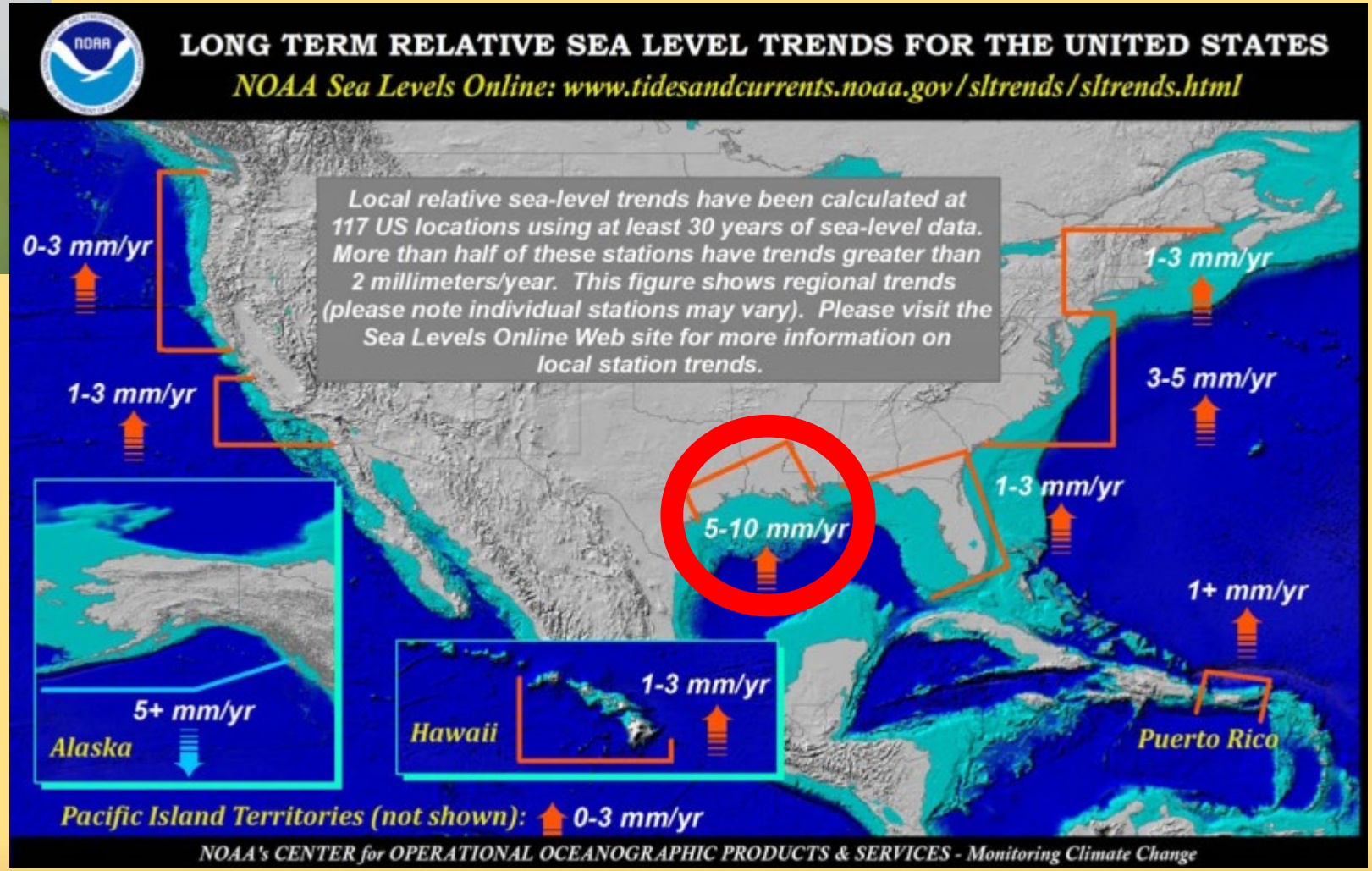




Channelization and leveeing of the Mississippi leads to loss of critically needed sediments to counterbalance subsidence

Relative Sea-Level Trends Where I'm from

Measured by tide gauges



The Mississippi Delta's present problem stems from subsidence, not eustatic sea level rise

Declining Sediment loads in the Lower Mississippi River

- Prior to 1960 sediment loads consistently above 500 mg/l
- From 1960 to 1990 sediment loads fell to 200 mg/l
- “The 40-70% decline in the last half century has been attributed to the construction of dams on major tributaries, artificial levees, river straightening, wing dams, bank revetments, and soil conservation practices.”

Source: Allison & Meselhe, 2010

The Transformation of the Mississippi River: The Future

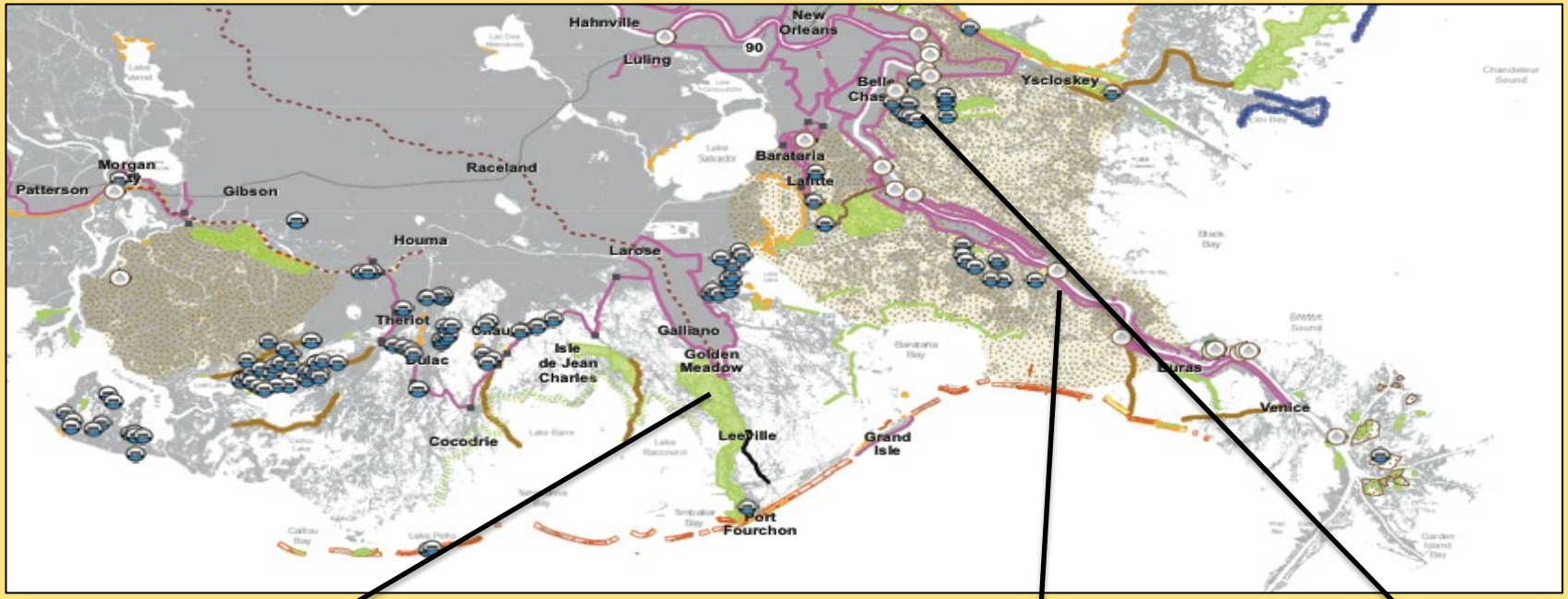
Year - 2009

Year - 2100

Map: Blum, M.D., and H.H. Roberts (2009), Drowning of the Mississippi delta due to insufficient sediment supply and global sea-level rise, *Nat. Geosci.*, 2, 488-491.

Hydrological alterations accelerating impacts of sea level rise

Proposed Coastal Restoration in the Mississippi Delta



Flood Control Structures

Creating Marsh with Dredging

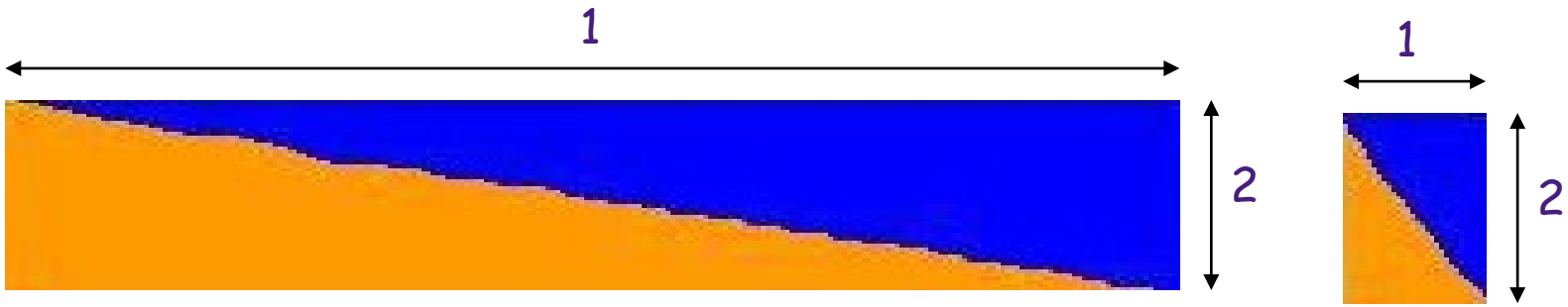
Creating Fastlands with Levees

Diverting River Water & Sediment

Source: Louisiana Coastal Restoration & Protection Authority

Slope is Critical

- A given rise in mean sea level will have greater effect when the slope of the shore is gradual
- Example below illustrates the effect of equal rise in sea level in places of different slope

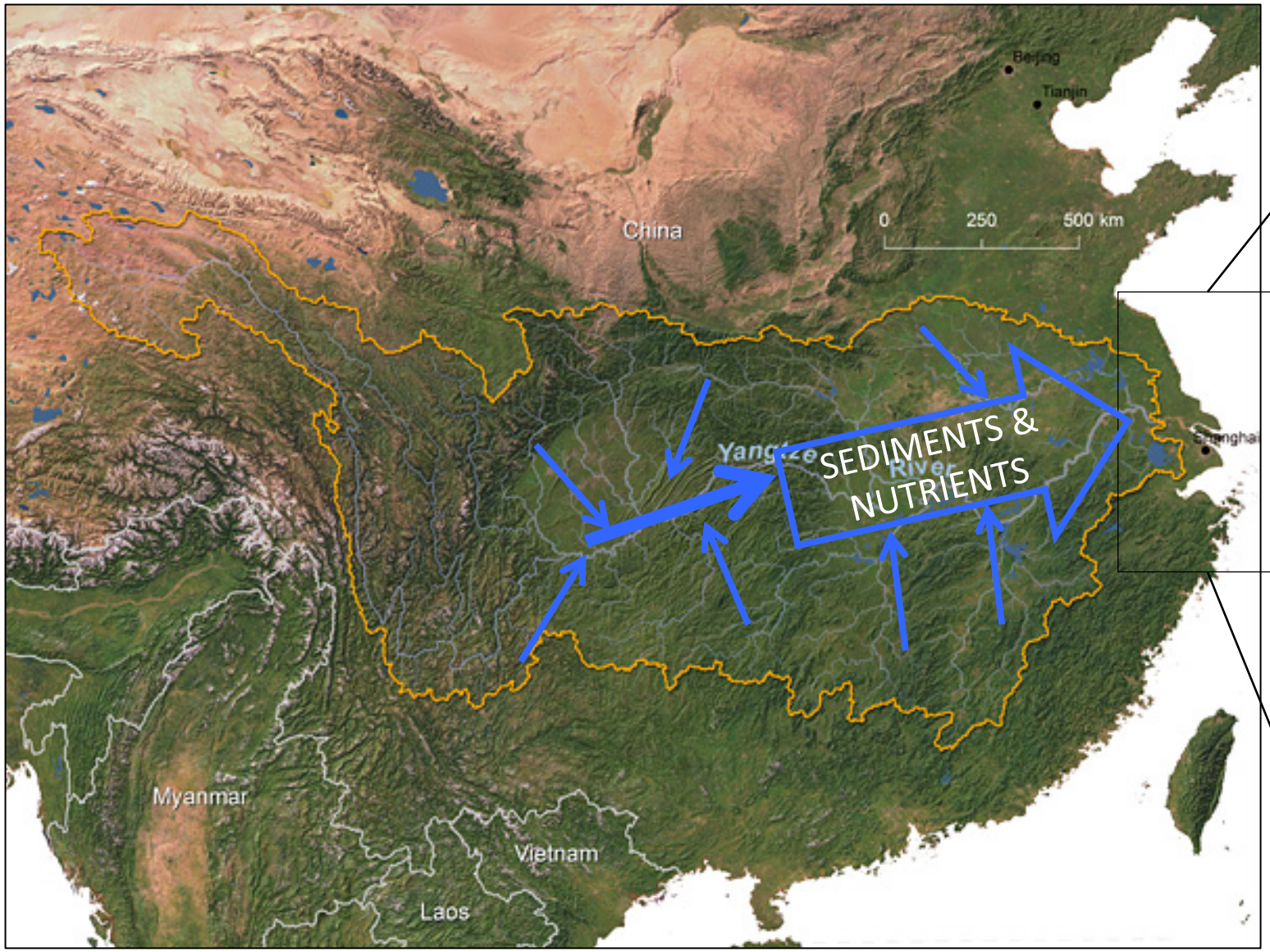


1 – Landward Encroachment of Sea

2 – Sea Level Rise

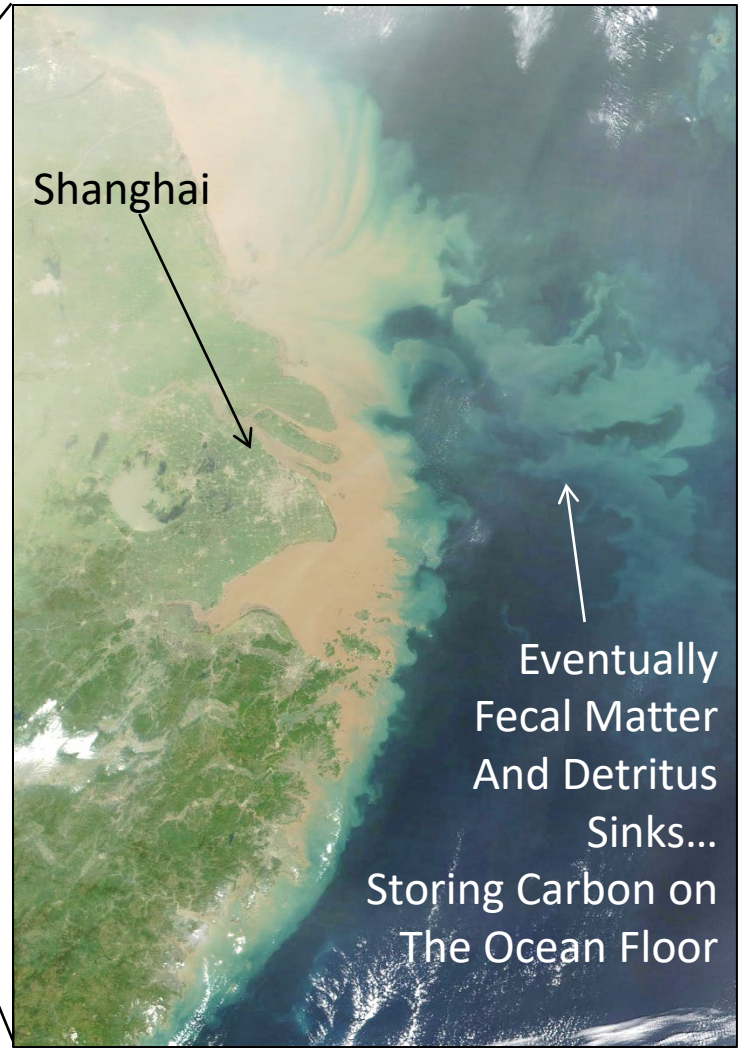
MAP OF YANGTZE DRAINAGE BASIN IN CHINA:

Sediments, nutrients, and organic matter from the watershed flow into the river. Eventually these materials enter the sea and nourish coastal ecosystems, which sequesters carbon.



Source: http://www.globalrivers.org/wp-content/uploads/2011/10Yangtze.jpg

Satellite Image of Sediment Plume in The Yangtze Delta, April 2002

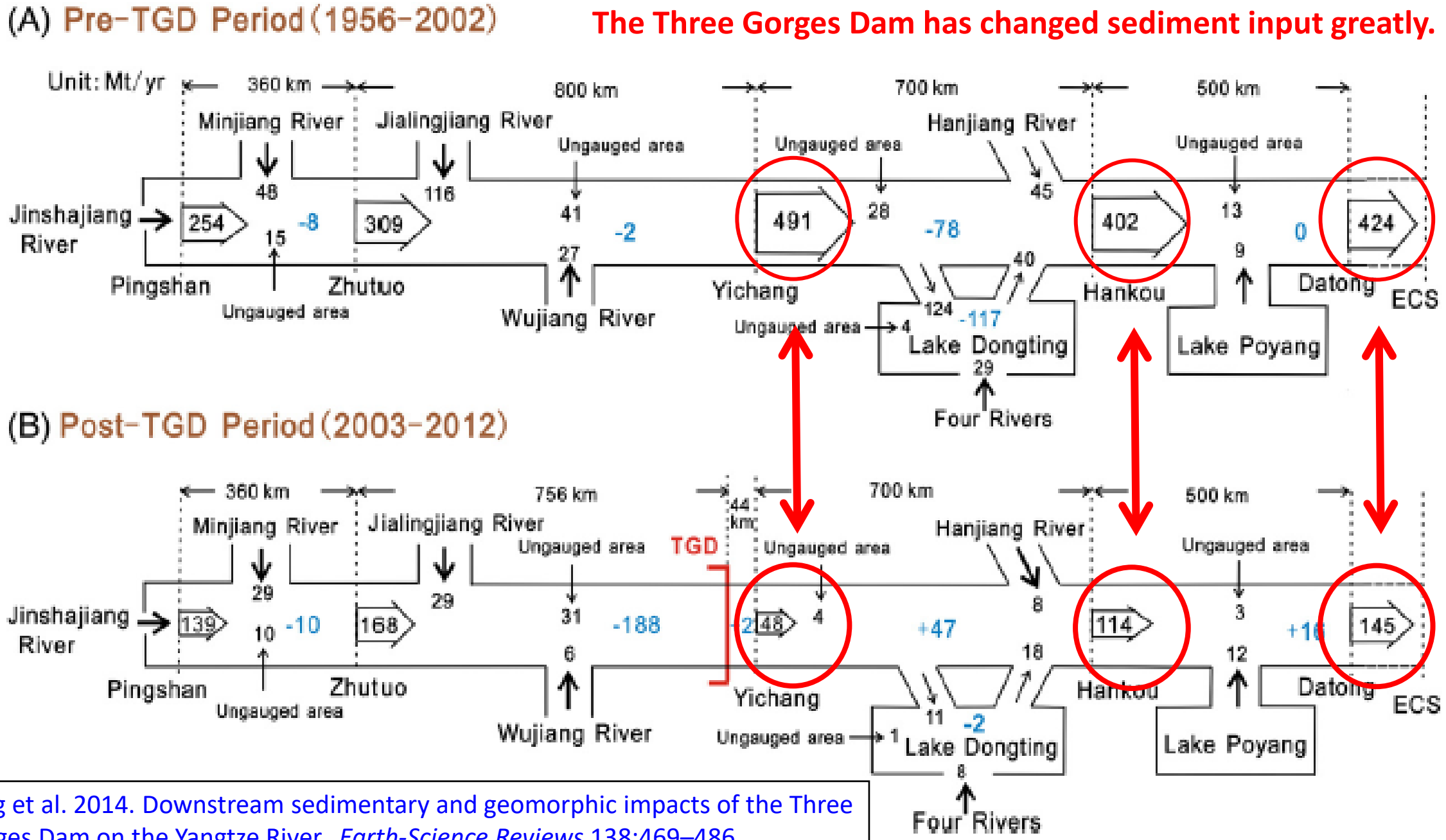


Source: NASA Earth Observatory

Yangtze River – Three Gorges Dam

- Largest Electric Power Facility In the World
- “Renewable” energy
- Cost: 180 Billion Yuan ($22.5 Billion USD)
- Construction Started: 1994
- Completed: 2012
- Electricity Gen. 80-100 TWh
- Width 2.3 km
- Concrete: 27.2 Million m^3
- Payback of Construction reached after 1000 TWh has been generated (~12 years)

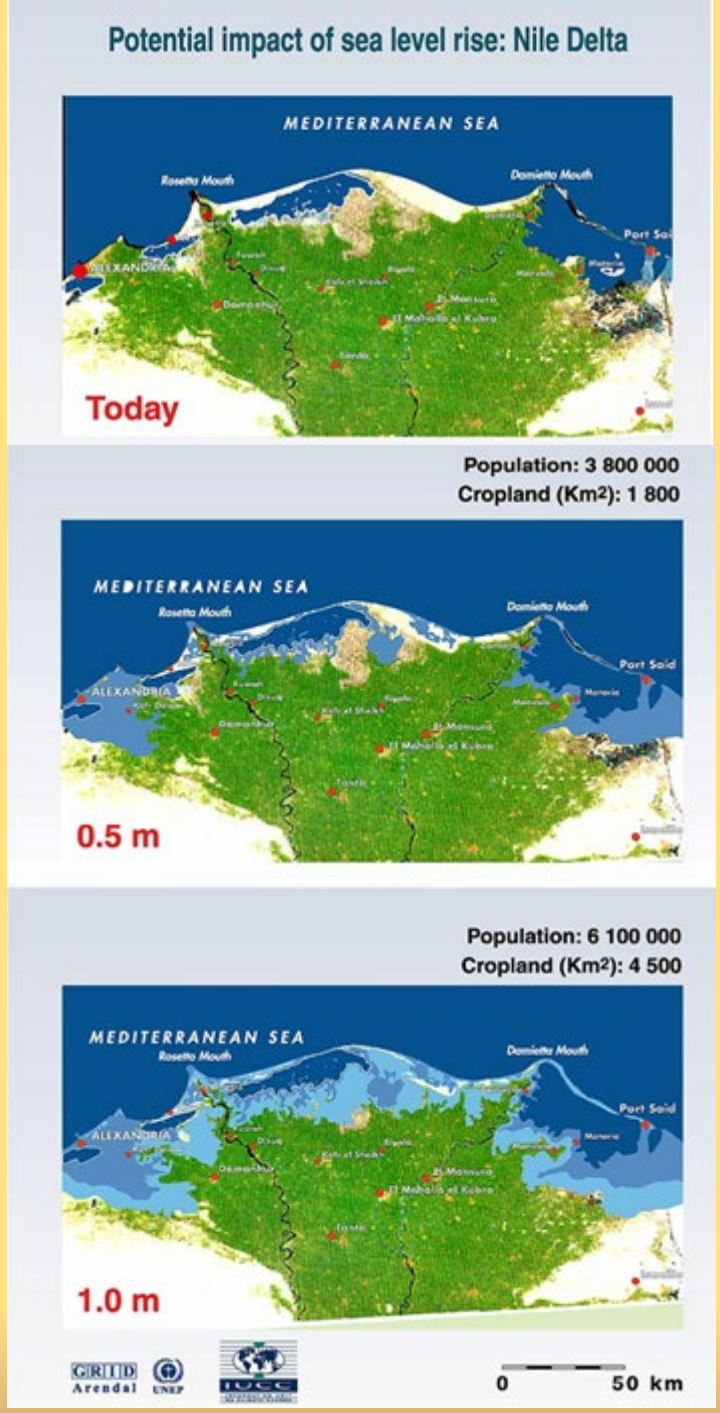
The Three Gorges Dam has changed sediment input greatly.



Yang et al. 2014. Downstream sedimentary and geomorphic impacts of the Three Gorges Dam on the Yangtze River. *Earth-Science Reviews* 138:469–486.

Nile Delta

- Prospects are not encouraging
- Even a relatively modest MSL rise of 0.5 m causes substantial loss of land
- Question is: *even so, would it have been done differently knowing then what we know now?*



Calfed Bay-Delta Program

- Cooperative effort includes Federal Government, State of California, local governments and water users, to address water management and aquatic ecosystem needs of California's Central Valley
- Sacramento-San Joaquin Delta drains west into San Francisco Bay
- Nation's largest water delivery system, providing drinking water to 25 million Californians

The Bottom Line

- Deltas the world over are threatened by sea level rise
- While sea level rise from global warming is a concern, other causes exist such as human alteration of the hydrologic cycle and sediment “starvation” of deltas
- Global change is not just global warming
- The Mississippi Delta has a big challenge
- Will future resources be sufficient to “engineer” our way to coastal protection and restoration?