Notes for the

Expert Panel

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Baton Rouge

by

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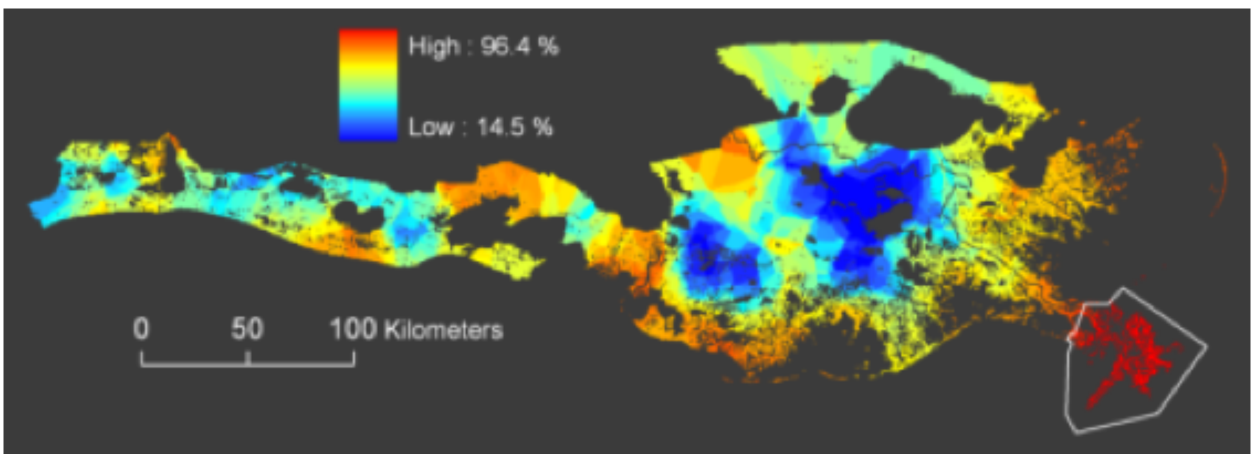
Five (5) discussion topics



The percent inorganic mineral matter (by weight) in soils of the Louisiana coastal zone from mineral (red) to organic (orange to yellow to blue) soils (from Tweel and Turner 2011). The red tip of the Mississippi River delta, outlined by a white line, is discussed, along with the consequences of diversion size, model output and climate change (sea level rise).

1. Organic and inorganic soils – the coast is not homogenous, and this has consequences

The coast is not homogenous with regards to soil quality and, therefore for restoration strategies. Most of the surface soils in the Louisiana coastal zone are comprised of organic sediments, not of inorganic matter (Figure 1). These organic soils overlay the deeper inorganic soils laid down as the river sediments prograded across the coastal landscape (Figure 2). The levee alongside the distributary channel is a mineral soil that accumulates as minerals settle out when water velocity slows during overbank flooding. Emergent vegetation grows when the water depth is shallow enough to root and flourish. The transition from inorganic to organic soil is an 'ecosystem transition' – a switch - in which it is the accumulation of organics that keeps pace with relative changes in sea level.

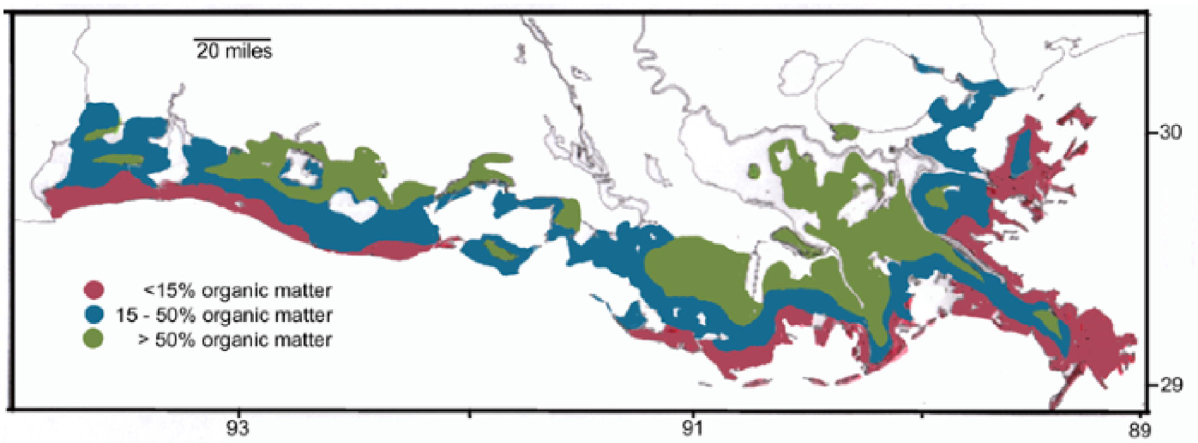


Figure 1 – The percent inorganic mineral matter (by weight) in soils of the Louisiana coastal zone (from Tweel and Turner 2011).

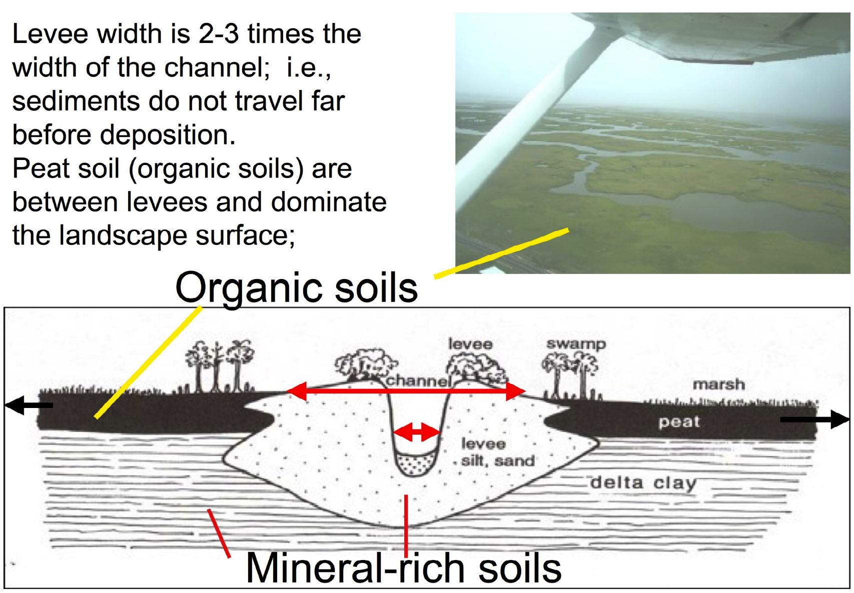


Figure 2 - Figure 2 – A profile of the distribution of organic and inorganic soils across a natural channel.

These organic soils are vulnerable to alterations in flooding duration, depth and frequency. They are, by definition, 'wet' lands whose 7,500 year presence on deltaic coasts throughout the work were tenuously balanced in an equilibrium of many coastal drivers, including salinity, storms, currents and hydrology. If dried too long, then the organics oxidize (e.g., much of New Orleans is below sea level because of drainage) and the land subsides. Flooded soils are not hospitable for plants - hence the minimum depth for establishment. The organic soils are the 'green toupee' lying above the mineral substrate.

Two stressors on these organic soils are dredging and nutrient loading higher than when they were formed.

Dredging relative deep canals and placing the dredged material alongside the canal blocks water movement above and belowground. The frequency of drying and flooding events diminishes, but the soils become drier for longer time periods and also flooded longer. As a result the land loss for the organic soils is directly related to dredging in time and space (Turner 1997; Figures 3 and 4).

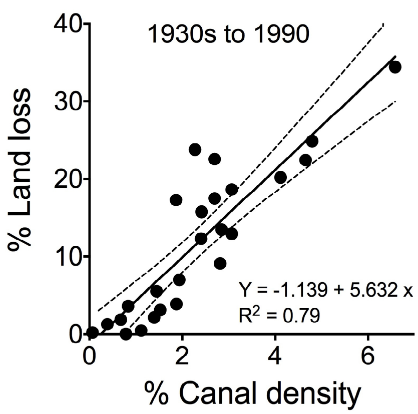


Figure 3 – Land loss vs. canal density in the deltaic plain. The data are for 15 minute quadrangle maps for the deltaic plain, except for maps with < 50% land area in the 1930s. The total area is 77% of the deltaic plain (4,970 mi^2).

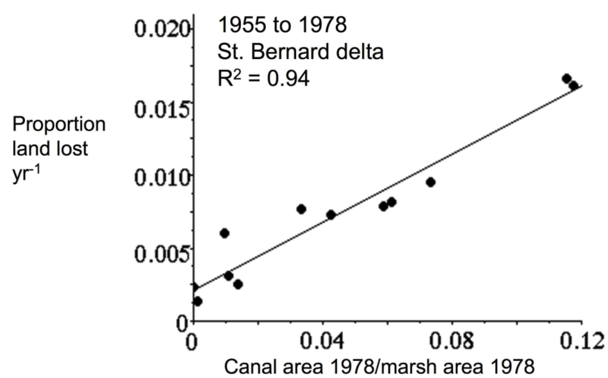


Figure 4 – Land loss vs. canal density in the St. Bernard delta. The data are for 7.5 minute quadrangle maps.

Nutrients can be a fertilizer for microbes, whose degradation of the organics accumulated over hundreds, if not thousands, of years is enhanced. Root biomass may be reduced as plants shift their energy allocation from foraging for scarce nutrients to producing more aboveground photosynthetic structure. The phenotypic adaptations may include alterations of root/shoot allocation, weaker biomechanical structures, shifts in carbohydrate/sugar formation and usage, and biological clock alterations, all of which promote succession towards floating and shallow rooted annuals that in turn accelerates decomposition, and contributes to reduced soil strength and susceptibility to erosion (Swarzenski et al. 2008, Turner 2011, Deegan et al. 2012; Figure 5). The nutrient concentration in the Mississippi River are much higher than when these wetlands formed (Broussard and Turner 2009; Turner et al. 2007).

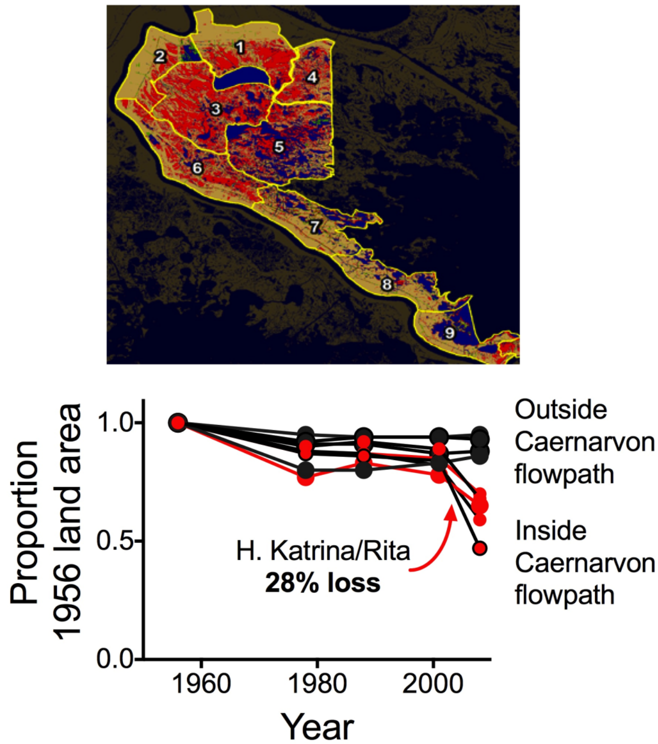


Figure 5 - Land loss (red) in the flowpath of the Caernarvon diversion (from data in Suir et al. 2012). The loss of one third of the wetlands in the flowpath of the diversion has been linked to the enhanced nitrogen and phosphorous content of the river.

2. Mineral soils – It's a 'zero sum game'

The wetland soils of the Mississippi River bird foot delta, in contrast, are mineral soils. The loss and gain of wetlands there are in a balance between the supply of mineral materials (sediment loading), the subsidence rate, sea level rise, capture efficiency, and soil stability. The supply of inorganic minerals (sediments) from the watershed has an important influence of the land gain and loss of the mineral soils on the coast. This supply has fluctuated greatly over the last two hundred years. The major driver of these fluctuations over the last 200 years has been landuse.

The sediment yield of watersheds is, in general, inversely related to its vegetative cover through the effects on canopy cover and the loss of the accumulated carbon on and within the soil. Vegetation cover was grossly reduced in the Mississippi River Basin (MRB) during the 1800s as the population of the Midwest grew from no more than 106,000 in the early 1600s to 1 to 10 persons km^{-2} by the 1850s when the population center of the US crossed the Appalachian Mountains and headed into the MRB in a west-southwest trajectory.

The new colonists brought with them row farming at an intensity previously unknown to these lands and this switch to higher-intensity farming happened quickly. Row crop cultivation meant that existing vegetation was removed and the soil surface severely disrupted and compacted. Livestock roamed the woods for forage and further disrupted the soil surface. A visitor in the 1800s noted that:

> "There is no portion of the globe that is being exhausted of its fertility by injudicious cultivation, so rapidly as the Mississippi Valley" (Bateham 1849, cited in Whiteney, 1994, pg. 226).

The amounts of soil loss under cultivation could be staggering and develop quickly (Figure 6). A 1928 USDA publication on soil erosion (Bennett and Chapline 1928) described how an apple orchard near Lookout Mountain in northeastern Kansas had the trunks of trees completely buried by overwash of silt from neighboring lands, and that the level of ground was at the branches for the trees, and there were gullies 300 feet wide in places, and 3/4th of a mile long.

Figure 6 – Soil erosion examples. Left: Providence Canyon State Park, Georgia. The gullies are 150 ft deep and several hundred yards wide in places. These are relics from 'poor farming practices during the 1800s (Sutter 2010). Right: National Archives photo 114 SC 5089, Soil Conservation Service "Buried machinery in barn lot. Dallas, South Dakota. May 13, 1936."

These massive changes meant that sediments, including soil organic matter, were washed off the land and into small creeks, rivers, and, at least some extent, to the coastal zone. The recognition of the seriousness of soil erosion led to the formation of the Soil Erosion Service (re-named the Soil Conservation Service in 1935), the classic 1934 Reconnaissance Erosion Survey, and the classic USDA publication 'Soils and Men' (e.g., Bennet and Lowdermilk 1938).

This agricultural expansion resulted in a significant increase in the sediment yield of the Mississippi River Basin (MRB) (Figure 7). The suspended sediment concentration at New Orleans was about twice that before the 1870s. The values declined after 1910, and especially so after the period of extensive dam construction that began in the early 1950s on the Missouri River. The 170 year river discharge record at Vicksburg demonstrates no permanent rise or fall in the annual discharge volume that would affect this general interpretation.

The size of the MRD responded to these sediment loadings and in a proportional manner (Figure 8 and 9). The delta was narrow at the time of the European arrival, but then thickened with increased sediment load (Figure 8). The size then decreased as the sediment load decreased, but with a shorter response time than that of its growth phase.

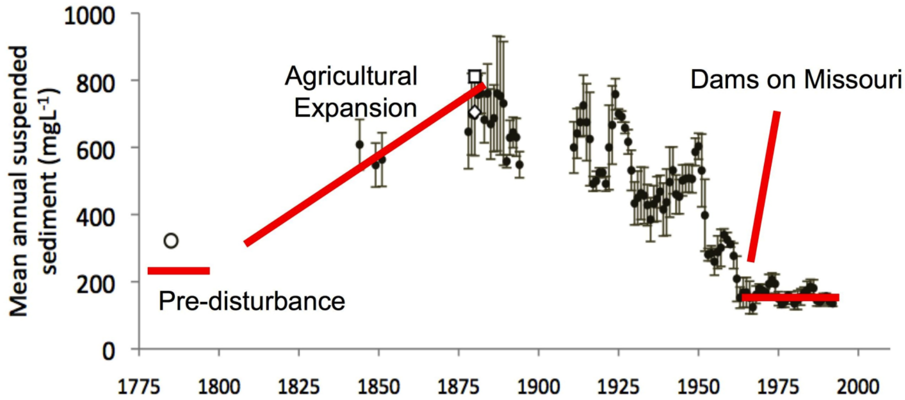


Figure 7 – Suspended sediment concentrations concentration @ New Orleans – from before Europeans arrived to present (from Tweel and Turner 2011).

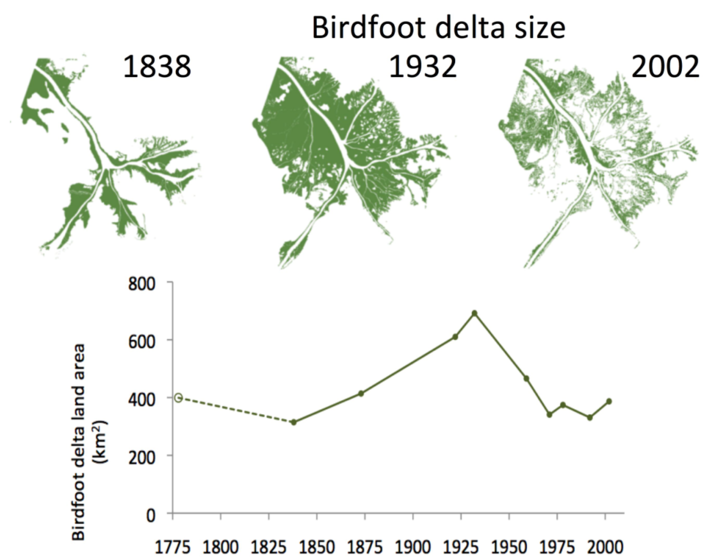


Figure 8 –The size of the bird foot delta from before Europeans arrived to present (from Tweel and Turner 2012).

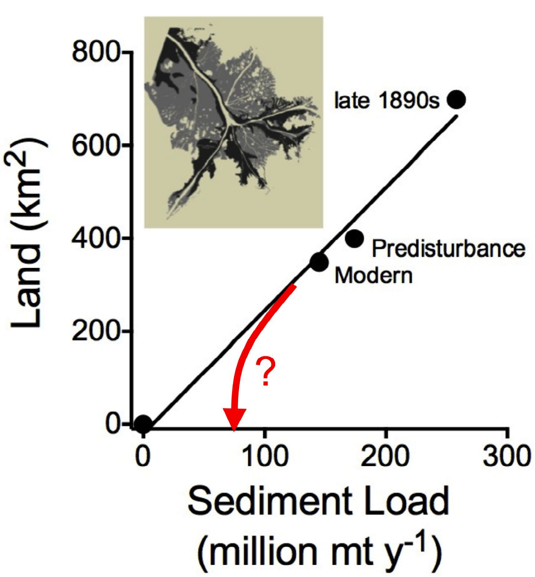


Figure 9 – The size of the bird foot delta and sediment load for the data in the previous two figures (from data in Tweel and Turner 2012). The X, Y intercept of 0, 0 is an assumption.

The size of the bird foot delta changed in proportion to the sediment load (Figure 9). It is possible that the land area will be zero *before* the sediment load is zero (a system collapse).[1]

It is important to know that the distribution of sediment supply in the lower Mississippi River does not all go offshore (Allison et al. 2012). Sixty-seven percent (67%) of the sediment load at Belle Chasse, LA enters the Gulf of Mexico through the measured passes (Figure 10). About 33% enters various channels on the river and can be considered another 'diversion' in the sense that the mineral soils there accumulate and sustain the land. It is this 33% that sustains the existing (wet)land in the lower Mississippi River delta at Bohemia, Ostrica, Ft. St. Philip, Grand Pass, Baptiste Collette, Cubit's Gap, West Bay, and the small cuts to the south, but above the Head of Passes. Reducing the sediment load to any of the channel openings before it reaches the Gulf of Mexico will reduce the amount of land. The total amount of land in the bird foot delta is 152 mi^2, depending on where the boundary is drawn. One implication of these measurements over time and space is that the size of the Mississippi River Delta (MRD) is directly dependent on sediment load.

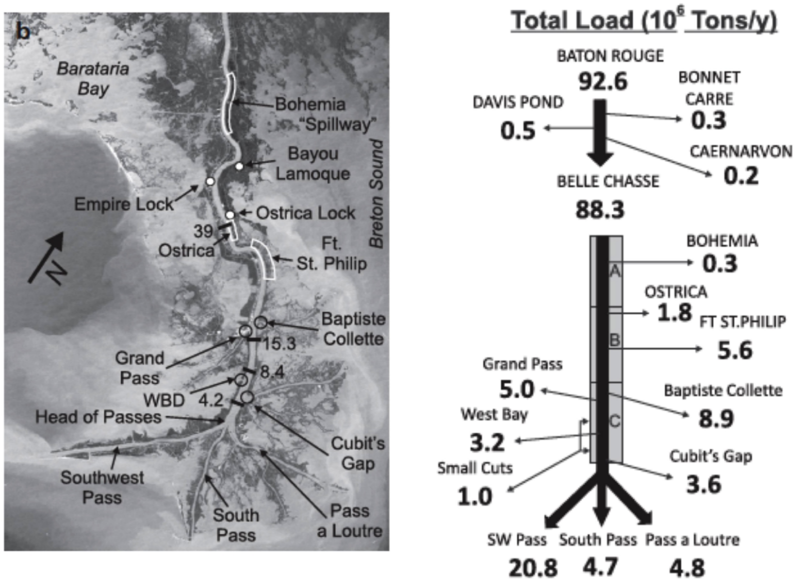


Figure 10 – The distribution of total sediment loading south of Baton Rouge for the flood years of 2008-2011.
Thirty percent (30.3) % of the total load exits the three southern passes, but only nine percent (9%) of the sand (distribution not shown). (from Allison et al. 2012, figure 7).

A major conclusion, therefore, is that the balance of sediment load distribution to the coast is that of a 'zero-sum' game for the MRD, including lower Plaquemines Parish, where the MRD is a 'hurricane speed bump' for New Orleans and where the commerce of the Mississippi River passes through.

[1] Note: the relationship does not apply to wetland area in the rest of the deltaic plain whose areal changes are not coincidental with those at the bird foot delta. The area of the Mississippi delta plain is about 3726 mi^2, of which 152 mi^2 is in the bird foot delta shown in this figure.

3. Model land gain/loss estimates

The results of modeling diversion growth under various scenarios are in the Master Plan, Appendix A2. The planned diversions into organic and inorganic soils is a new engineering approach to river management because of their scale, expense, location and other factors. The 'natural' deposition of river sediments before Europeans involved a broad overbank flooding with sediments falling out close to the river channel, hence the levee (Figure 2). The 'crevasses' after construction of the flood protection levees are explosive releases of hydraulic energy through relatively narrow openings. Kesel estimated that the pre-european overbank flooding was 4.9 million mt y^{-1}, which is slightly less than the amount deposited during hurricanes (Tweel and Turner 2014). One proposed 50,000 cfs diversion would introduce about 27.4 mt y^{-1}.

There are two large diversion with credentialed estimates of land loss in the diversion flow path. One is the Caernarvon diversion mentioned earlier (Kearney et al. 2011; Figure 5). Another is by Suir et al. (2012). They measured the amount of land for a natural crevasse at Ft. St. Philip, located between Venice and Port Sulphur, on the east back of the Mississippi River. This crevasse formed around 1973 when the river stage was at a record peak height. The amount of water flowing through the opening now accounts for about 100 to 130 thousand cfs, amounting to 6.3% of the river flow in 2008-2001. These conditions make it comparable to the size of proposed diversions in the most recent Master Plan. The amount of land north and south of this diversion was also measured, as well as for sections of the entire east bank, including the Mississippi River delta.

The cumulative loss of land (no gain) by 1988 was a 52% of the land existing in 1956, and it had not been restored by 2008 (Figure 11). The amount of land in the Ft. St. Philip area was much lower than in either area adjoining the Ft. St. Philip diversion site and there was no restoration. The authors described the results this way:

"the crevassing of the eastern bank of the Mississippi River levee was a *loss accelerant* in the Fort St. Philip area." (emphasis added)

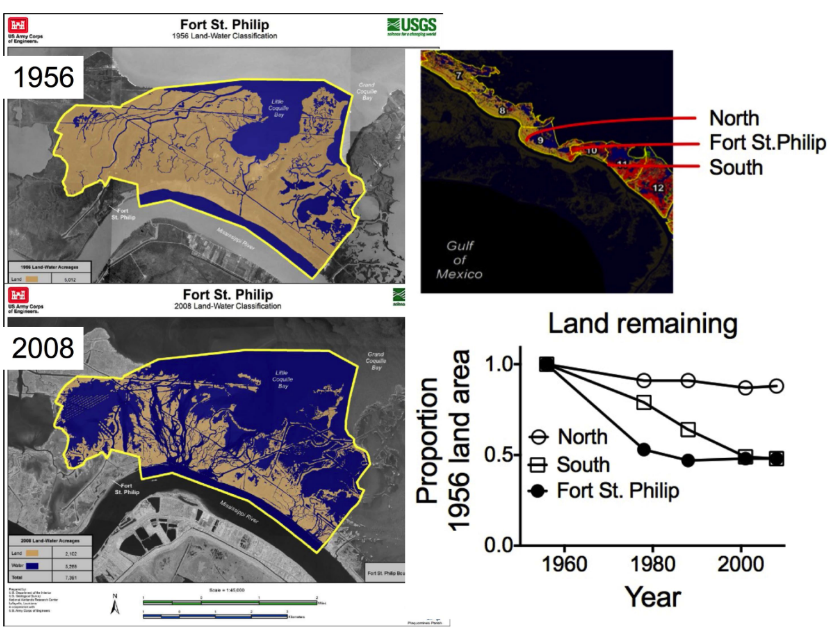


Figure 11 – Left: the land in the Fort St. Philip area in 1956 and 2008; Right: The cumulative loss of land by interval in the study area and north and south of the crevasses.

A comparison of land gain/loss in the lower Mississippi River delta is in Figure 12. Both the Caernarvon and Fort St. Philip diversions lost huge amounts of land (33% and 52% respectively), but at different periods after the diversion. The Caernarvon diversion started in 1992, but the land loss was during Hurricanes Katrina/Rita in 2010. The Fort St. Philip land loss began around 1973. Neither show signs of recovery.

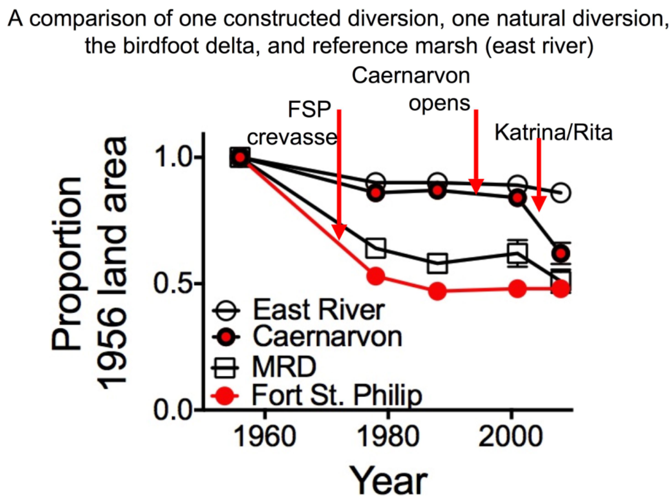


Figure 12 – A comparison land loss by 2008 at the Caernarvon diversion (33%), the Fort St. Philip 'natural' diversion (52%), the bird foot delta (49%), and the background rate along the east bank of the Mississippi River (11%) as a percent of the land present in 1956. (data from Suir et al. 2014). The timing and amounts of land lost in the flowpath of the Caernarvon diversion are comparable to those described in Kearney et al. (2011, 2014).

This result informs our expectations about the success of similarly-sized diversions proposed in these soils at the interface of the organic and inorganic soil outlined in Figure 1.

Another approach is to compare the modeled estimate with the historical growth of the delta over the last 7,500 years. A 50,000 cfs diversion operating 10% of the time would bring 0.83% of the average annual water flux into the diversion flow path. Although this is a lot of water to divert from an engineering point of view, 0.83% of the discharge prorated over 7,500 years of land gain (1.5 million ha) is 2.7 acres per year (assuming the diversion is open 10% of the year). This compares with the estimate in the Master Plan. Appendix 2A, page SE-8 of the 2012 State Master Plan Mid-Barataria for a diversion of 50,000 cfs, which is that it would build 2,944 (less optimistic) to 7,089 (moderate) acres after 20 years. The moderate estimate comes out to ~ 150 - 350 Acres per year (if we assume uniform growth).

The modeled land gain is about 100 times the historical record which took place in an era of declining sea level rise, not the acceleration of sea level rise currently underway. There are two modern examples of river diversions that led to significant losses, not gains. I think that these differences between model and the on-the-ground examples need a quantitative explanation.

The existing models could be validated (suggested above) by demonstrating that the existing models can accurately describe the land loss at Fort St. Philip, the changes at the MRD birdfoot, and the 7,500 years average land gain.

4. Model scaling of diversion benefits and costs

The various estimates of the anticipated land gain are the result of rather large changes in scale, ranging from a few thousand cfs to 250,000 cfs, and costs in the range of 10 million to 10 billion dollars. We can assume that the costs may rise for the usual suite of reasons that seem to plague large engineering projects. Neglecting those cost challenges, though, still reveals some outcomes in the anticipated benefits (land gain). Two of these are shown in Figure 13. Both show that the presumed benefits decline with increasing project size. These demonstrate an inverse economies of scale.

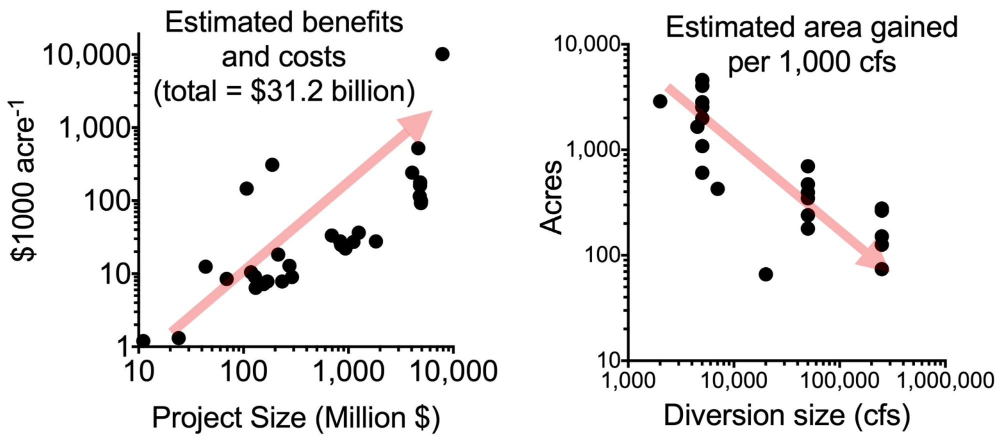


Figure - 13. The changes in benefits presumed (accepting the estimates) for the range of project size (left) and diversion size (right). The cost per area increases logarithmically with size and the benefit per water diverted declines logarithmically with size. These demonstrate an inverse economies of scale.

Turner and Boyer (1997) offered three reasons for this relationship. As scale increases, the cost go up because of uncertainties in:

- •how to control ecosystem behavior (predictability and use),
- •ecosystem complexity,
- •incomplete ecosystem knowledge (regional, not just local)

The engineering 'solutions' to meet these uncertainties is more engineering. This is not unreasonable, and follows precedence to protect navigation, safety, and to meet project goals with reduced risk of failure. But it means that the efficiency of land gain per dollar or per water diverted is less optimal with greater project size. Many small diversions appear to be more effective than a few large diversions.

5. Climate change

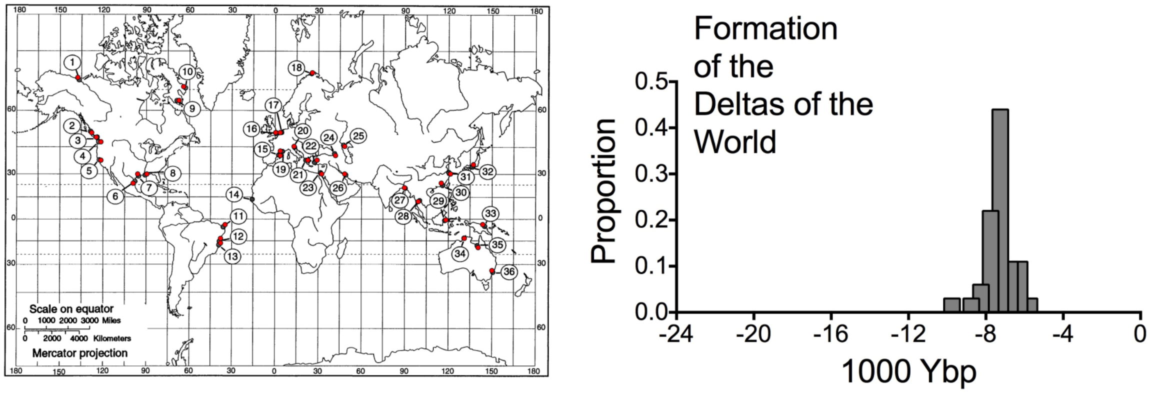


Figure - 14. The location of 36 deltas and the frequency of binned data (500 year intervals; from Stanley and Warne 1994).

The age of thirty-six (36) deltas throughout the world (Figure 14 are based on the dated horizon where delta pro-gradation began. These deltas are in micro- and macrotidal environments, and in Arctic and Equatorial climates, and do and do not have mineral recovery efforts ongoing. The age of these deltas is 7244 ± 117 ybp (mean ± 1 SE). The age of the Mississippi River delta in this analysis is 7306 years. Their appearance is the result of reaching a tipping point in the balance of sediment supply, erosion, and relative sea level rise.

The age when these 36 river deltas formed is coincidental with a slow down in sea level rise Figure 15). The coincidence delta formation and sea level rise deceleration supports the conclusion that a acceleration of sea level rise will be detrimental to the restoration of the coast, and fatally so when sea level rise reaches the tipping point.

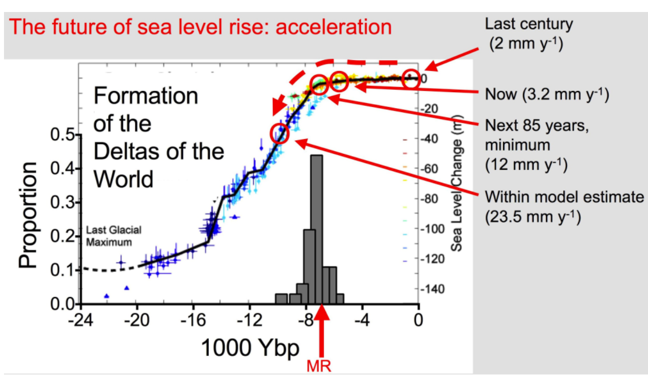


Figure 15 – The coincidental progradation of riverine deltas and the slow down in sea level rise. The recent and projected sea level rise rates are indicated and their approximate position on the historical record of sea level.

The scenario for delta survival by the end of this century is unequivocally bleak without significant and quick global action to reduce greenhouse gases. All the reasonable scenarios, which are conservative scenarios, have the 'likely' sea level rise scenario at the cusp of where the world's deltas formed 7,500 years ago (Figure 15). The 2012 Master Plan acknowledges the possibility of a sea level rise of 13 mm y^{-1}, but currently includes a 'less optimistic' estimate of 9 mm y^{-1}. This is at or near the tipping point in Figure 15. Projections by the US National Research Council (2010) suggest possible sea level rise over the 21st century of between 56 and 200 cm.

Church et al. (2013), the authors of the IPCC WGI AR5 chapter on ‘Sea-Level Change’ projected that sea level rise would be 0.52 to 0.98 m by 2100 (0.75 m). The ‘likely rate of rise was 8 to 16 mm y^{-1} for 2080 to 2100 (mid-range 12 mm y^{-1}). They say that ‘in the calibrated uncertainty language of the IPCC, this assessed likelihood means that there is roughly a one-third probability that sea-level rise by 2100 may lie outside of the “likely” range. That is, the AR5 did not exclude the possibility of higher sea levels.”

It is only prudent to acknowledge that the IPCC estimates of sea level rise and temperature change usually underestimate what eventually occurs (Horton et al. 2014). It was recently announced, for example (12 May 2014), that two teams of scientists said that the long-feared collapse of the Antarctica Ice Sheet had started, beginning what will be a centuries-long, "unstoppable" process that could raise sea levels by 1.2 to 3.6 m (Rignot et al. 2014, Joughin et al. 2014).

This rather unforgiving scenario is what seems to be playing out without an immediate reduction in greenhouse gasses. It may be that the retreat of the coast along the sea level curve in Figure 15 will not be a mirror of the ascent (land gain). Caribbean mangrove wetlands have persisted for thousands of years with only trace amounts of inorganics in them (e.g., McKee et al. 2007). The interlobe deposits of the Mississippi River have also survived in a low-nutrient environment for thousands of years (until now). Strongly embracing the assurance that we don’t know much (an ignorance-based world view) about the multitude of uncertainties and major risks might serve us well to plan for the future with optimal use of existing resources (Turner 2009).

6. Implications for the future of the Mississippi River delta – ‘do no harm’

1) Soil erosion from forest loss, urbanization and agricultural disturbances is well documented for many locations and over many centuries. The agricultural expansion of the Mississippi River watershed in the 1800s led to gully formation and soil losses that were widely observed as trees were cut down, with plowing, and as row crops replaced perennial plants. The sediment erosion led to a doubling of sediment loading to the Mississippi River bird foot delta by the late 1800s. It declined precipitously when dams were built after WWII, principally on the Missouri River.

2) The equilibrium of land gain or loss at the bird foot delta is directly dependent on the sediment loading. There is, in other words, an equilibrium in the sediment balance south of Port Sulphur, LA. The birdfoot delta is, in other words, a ‘diversion’ – and it is a zero sum game of sediment allocation.

3) It is possible that a system collapse (no land) might occur at the mouth of the river before the sediment load reaches zero.

4) There are proportional consequences that are larger than the diversion ‘footprint’ once diverted water leaves the main channel. Two examples are: a) A diversion of sediments upstream will result in less sediment going downstream and wetland loss. B) the diversion of sediments into the Atchafalaya increases the size of the Wax Lake and Atchafalaya deltas. Both come at some expense to the size of the

MRD. Learn how to quantify the trade-offs of moving sediment from one basin to another (1:3 gain, or 3:1?), of the effects downstream of diverting sediment upstream, etc. Another example, does a 20% sand diversion upstream mean that dredging a navigation channel downstream is less demanding for a decade or so, but also leads to birdfoot delta collapse after 30 years? These are tractable modeling problems to address.

5) The increased sediment loading from a diversion to a specific area *may* build land from open water when mineral matter is being added to a mineral platform. But, most proposed river diversions are planned for organic soils (most of the deltaic plain is an organic 'green toupee overlying mineral soil). Land loss rates from the 1930s to 2001 in these organic wetlands of the coast are directly proportional to dredging activities in a dose-response manner. We should be careful, therefore, to avoid minimizing the differences in soil types, and appreciate the differences. A small land gain near the diversion may be relatively insignificant compared to the wetland loss in the organic soils downstream in the flowpath, as it was in the case of the Caernarvon diversion at Big Mar. The result (loss) is certainly a plausible outcome of loading nutrients (N and P) into the organic soil matrix that comprises most of the deltaic plain.

6) The Wax Lake and Atchafalaya deltas are not good models for a diversion of water and sediments into organic soils. Indeed, the natural crevasse (100-130 thousand cfs) at Fort St. Philip has been described as a "loss accelerant" because it has not regained the 52% land lost when it opened in 1973. This amount is in the same range as the 33% loss in the flowpath of the smaller Caernarvon diversion.

7) If one accepts the logic that coastal wetlands provide protection from hurricanes, then the further south the MRD extends, the greater the protection for the city of New Orleans and inhabitants and industry to the south.

8) There is an inverse relationship between project size and benefits (as estimated fro, the models, but see item #9). This is an inverse economy of scale using these data. If the model estimates are correct, then many small diversion projects will yield more benefits than a few large diversion projects.

9) The modeled estimates of land gained from the diversions during an era of accelerating sea level rise is 2 orders of magnitude higher than the record of land gain over 7,500 years during an era of declining sea level rise. The results of two large diversions (Caernarvon and Fort St. Philip) were massive land losses. The discrepancy between these observations and the model results needs to be examined quantitatively. A quantitative test of the model is to use it to predict the outcome at Fort St. Philip and the 200 year history of land gain/loss at the MRD.

10) The outlook is not favorable for either organic or inorganic systems when one considers that sea level rise is accelerating and will be at the tipping point of delta formation (7,500 ybp). The proposed 'benefits' of river diversions need to be

couched in terms of the 50 to 100 year sea level rise risk, not just the 20 year planning horizon.

7. References

Allison, M.A., C.R. Demas, B.A. Ebersole, B.A. Kleisss, C.D. Little, E.A. Meselhe, N.J. Powell, T.C. Pratt, and B.M. Vosburg 2012. A water and sediment budget for the lower Mississippi-Atchafalaya River in flood years 2008-2010: Implications for sediment discharge to the oceans and coastal restoration in Louisiana **J. Hydrology** 432: 84-97.

Bennett, H.H., and W.C. Lowdermilk 1938. General aspects of the soil-erosion problem. Pages 581-608, In: Soils and Men, USDA Yearbook of Agriculture. US Dept. Agriculture, D.C.

Bennett H.H., and W.R. Chapline 1928. The Problem of Soil Erosion. United States Department of Agriculture Circular 33, pp. 1-23.

Broussard, W., and R.E. Turner 2009. A century of changing land use and water quality relationships in the continental U.S. **Frontiers Ecology Environment** 7: 302-307. doi:10.1890/080085.

Church, J.A., P.U. Clark A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Pyne, W.T. Pffeffer, D. Stammer, and A.S. Unnikrishnan 2014. Sea-level rise by 2100. **Science** 342: 1445.

Deegan, L.A., D.S. Johnson, R.S. Warren, B.J. Peterson, J.W. Fleeger, S. Fagherazzi, and W.M. Wollheim. 2012. Coastal eutrophication as a driver of salt marsh loss. **Nature** 490: 388-392.

Frazier, D.E. 1967. Recent deltaic deposits of the Mississippi River, their development and chronology. **Transactions Gulf Coast Association Geological Societies** 17: 287-315.

Horton, B.P., S. Rahmstorf, S.E. Engelhart, and A.C. Kemp 2014. Expert assessment of sea-level rise by AD 2100 and AD 2300. **Quaternary Science Reviews** 84: 1-6.

Joughin, I., B. E. Smith, and B. Medley 2014. Marine Ice Sheet Collapse Potentially Underway for the Thwaites Glacier Basin, West Antarctica. **Science** 344: 735-738. DOI: 10.1126/science.1249055

Kearney, M.S., C.A. Riter, and R.E. Turner 2011. Freshwater diversions for marsh restoration in Louisiana: Twenty-six years of changing vegetative cover and marsh area. **Geophys. Res. Lett.** 38, L16405, doi:10.1029/2011GL047847.

Kearney, K.S., J.C.A. Riter, and R.E. Turner 2014. Comment on: "Integrating successional ecology and the delta lobe cycle in wetland research and restoration" by Nyman (2014). **Estuaries Coasts**.

Kesel, R. H 1988. The decline in the suspended load of the Lower Mississippi River and its influence on adjacent wetlands. **Environmental Geology and Water Sciences** 11: 271-281.

McKee, K.L., D.R. Cahoon, and I.C. Feller 2007. Caribbean mangroves adjust to rising sea level through biotic controls on change in soil elevation. **Global Ecology Biogeography** 16: 545–556.

Rignot, E., J. Mouginot, M. Morlighem, H. Seroussi, and B. Scheuchl 2014. Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler glaciers, West Antarctica, from 1992 to 2011. **Journal of Geophysical Research Letters** 41: 3502–3509.

Stanley, D.J. and A.G. Warne 1994. Worldwide initiation of holocene marine deltas by deceleration of sea-level rise. **Science** 265: 228-231.

Suir, G.M., W.R. Jones, A.L. Garber, and J.A. Barras 2014. Pictorial account and landscape evolution of the crevasses near Fort St. Philip, Louisiana. Mississippi River Valley Div., Engin.

Res. Development Center, Mississippi River Geomorphology and Potamology Program. MRG&P Report No. 2. Vicksburg, MS.

Sutter, P.S. 2010. What gullies mean: A Georgia's "Little Grand Canyon" and southern environmental history. **J. Southern History** LXXVI: 579-616.

Swarzenski C.M., T.W. Doyle, B. Fry, and T.G. Hargis 2008. Biogeochemical response of organic-rich freshwater marshes in the Louisiana delta plain to chronic river water influx. **Biogeochemistry** 90: 49-63.

Turner, R.E. 1997. Wetland loss in the northern Gulf of Mexico: Multiple working hypotheses. **Estuaries** 20: 1-13Turner, R.E. 2009. Doubt and the values of an ignorance-based world view for wetland restoration: Coastal Louisiana. **Estuaries Coasts** 32: 1054-1068.

Turner, R.E. 2011. Beneath the wetland canopy: Loss of soil marsh strength with increasing nutrient load. **Estuaries Coasts** 33: 1084-1093.

Turner, R.E. and M.E. Boyer 1997. Mississippi River diversions, coastal wetland restoration/creation and an economy of scale. **Ecological Engineering** 8: 117-128.

Turner, R.E., N.N. Rabalais, R.B. Alexander, G. McIsaac, and R.W. Howarth 2007. Characterization of nutrient and organic carbon and sediment loads and concentrations from the Mississippi River into the northern Gulf of Mexico. **Estuaries Coasts** 30: 773-790.

Turner, R.E., and N.N. Rabalais 2003. Linking landscape and water quality in the Mississippi River Basin for 200 years. **BioScience** 53: 563-572.

Tweel, A.W., and R.E. Turner 2012. Watershed land use and river engineering drive wetland formation and loss in the Mississippi River birdfoot delta. **Limnology Oceanography** 57: 18-28.

Tweel, A.W., and R.E. Turner 2014. Contribution of tropical cyclones to the sediment budget for coastal wetlands in Louisiana, USA. **Landscape Ecology** 29: 1083-1094.

Whiteney, G.G. 1994. From Coastal Wilderness to Fruited Plain: A History of Environmental Change in Temperate North America from 1500 to Present. Cambridge; Cambridge University Press.